Understanding Complex Systems

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Participatory Sensing, Opinions and Collective Awareness

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Foreword

In the 1980s there was considerable public concern and debate in the USA and Europe on the question of whether low-frequency (60 Hz), high-voltage electrical power lines were the cause of cancer clusters in housing situated close to the power lines. There were correlations noted between proximity of housing to power lines and clusters of incidences of cancer that seemed compelling evidence of cause for some people, but extensive studies fortunately have not shown any causative connection. People's understandable anxiety about their risk of developing cancer due to nearby power lines was based only on an average level of exposure due to the proximity of their housing to the power lines. Actual exposures over time at home or from other strong low-frequency fields generated by motors near their body at home or work, for example, were not measured and could not be measured for significant numbers of people. Thus, the history and cumulative exposure for individuals remained unknown. Regardless of the causative relationship to exposure, the lack of the ability to monitor or assess exposure to a perceived risk only adds to people's anxiety, rather than to strengthening their sense of agency and empowerment.

In contrast to the case of power line fields, people in many communities and circumstances are frequently or continuously exposed to conditions and materials that are known to be harmful to them directly (e.g. carbon monoxide), to local crops (e.g. ground-level ozone) and to the global climate (e.g. carbon dioxide).

Increasing awareness of personal exposure to environmental conditions and empowerment of citizens was central to the purpose of the EveryAware project on which this book, *Participatory Sensing, Opinions and Collective Awareness*, is based. The book describes new technologies that allow individuals to measure, respond to and visualise their own and others' exposure to noise and components of air pollution in near real time. But what is especially important, by also addressing the social and policy development aspects of citizen participation, the book does much more than providing a valuable look at technological challenges and solutions. Drawing on the three years of experience of the EveryAware project, the book lays out the project's innovative agenda. The project developed and tested novel sensor systems and software; incorporated citizens' use of quantitative sensor measurements and their subjective qualitative responses to conditions during measurements in their daily environment, rapid production, and feedback to users of the collected data in accessible visualisations; explored the implications of the technology as an enabler of meaningful participatory science and informed decision-making by stakeholders; and built and tested a web-based gaming platform as a new space or venue for empirical research by a wider research community.

Professor Vittorio Loreto directed the EveryAware project, which brought together a very capable and interesting group of partners starting in 2011 with funding from the EU Future and Emerging Technologies (FET) Open call in the 7th Framework Programme. The project was interdisciplinary and transdisciplinary in that it required not only effective integration and collaboration of researchers with diverse areas of disciplinary expertise but also of necessity dependent on successfully engaging with and learning from the experience of stakeholders in several communities under different conditions. This type of research is difficult to undertake, yet is essential in seeking to understand and address complex issues of global and local significance. It is also a challenge for funding agencies to issue calls for research that is on the one hand open enough to allow for potentially innovative project proposals and on the other hand has sufficiently defined criteria for judging the proposal and the project's progress by consensus amongst several reviewers with different areas of experience and expertise.

Over the past 4 years, I have enjoyed the opportunity to observe, evaluate, and learn from the genesis, development, and conclusion of this remarkable EveryAware project. I am very grateful to Vittorio and the people in the project. It has been a source of inspiration, insight, and delight for me.

It is my hope that this book in turn provides valuable information for readers and brings with it inspiration and insights to make further progress in combined technological and social innovation that can help society become aware of and address serious environmental concerns, as exemplified in this book.

April 2016 Ilan Chabay

Preface

The origin of this book is tightly linked with the EveryAware project that I had the honour to coordinate from 2011 to 2014 (www.everyaware.eu). EveryAware was funded by the European Commission under the big Future and Emerging Technologies (FET) umbrella (http://cordis.europa.eu/fp7/ict/programme/fet_en.html) and in particular the FET-Open scheme of the 7th Framework Programme. EveryAware has been a collective effort where different institutions and excellent senior and junior researchers teamed up with a common goal in mind: that of merging the opportunities offered by the Information and Communication Technologies (ICT) for participatory sensing with a scientific approach to the emergence of opinions and awareness. Somehow the red line informing the whole project is beautifully summarised by the following Chinese proverb:

Tell me, I forget.
Show me, I remember.
Involve me, I understand.

Thus, the general idea was that of involving nonskilled individuals in the very collection process of environmental data, much in the same spirit of the Citizen Science (Dickinson and Bonney 2015), but crucially coupling this activity with a systematic gathering of opinions about their perception of the urban environment, from various points of view (noise pollution, air quality, mobility efficiency, etc.). The integration of participatory sensing with the monitoring of subjective opinions, perhaps the true innovation EveryAware put forward, is crucial since it has the potential to expose the mechanisms through which the local perception of individuals of an environmental issue, corroborated by quantitative and personalised data, could evolve into socially shared opinions, eventually driving behavioural changes. With this aim in mind, EveryAware proposed a scientific agenda to the problem of enhancing environmental awareness using a wide range of tools going from Information and Communication Technologies, social information technologies, data science, and theoretical modelling, ending up with a new technological platform, the EveryAware platform (cs.everyaware.eu) that combines sensing technologies, networking applications, and data-processing tools. EveryAware put together a truly transdisciplinary effort to turn what appeared, since the very beginning, as a very ambitious and challenging project, in a concrete successful reality. Several institutions gave a key contribution in this endeavour, and I wish to take this opportunity to thank each and every one of them for the impressive boost they gave to the project. In particular, ISI Foundation in Turin (ISI) provided the coordination of the whole project; ISI Foundation, led by Francesca Tria along with Sapienza University of Rome (PHYS-SAPIENZA), led by Vito D.P. Servedio, gave a strong contribution in analysing and modelling the social dynamics generated by the project also solving fundamental problems in the aggregation of massive noisy quantitative and qualitative data; University College London, led by Muki Haklay, brought into the project its specialised expertise in community building through the use of Geographic Information Systems; the Flemish Institute for Technological Research in Antwerp (VITO), led by Jan Theunis, gave an important contribution in the domain of environmental monitoring and modelling, making sure that the results of the project were relevant and realistic with respect to the issue of sustainability; the Gottfried Wilhelm Leibniz Universität of Hannover (LUH), led by Gerd Stumme and Andreas Hotho, has been a strong computer science partner that put state of the art technologies and competences in data science to the service of the project. Finally, the CSP Consortium in Turin, an ISI subcontractor, gave a strong contribution in setting up the sensing devices adopted throughout the project.

The present book has been conceived within the EveryAware Consortium to provide the scientific community at large with the patrimony of knowledge acquired during the project so that further initiatives can flourish along the same direction. Its aim is that of presenting in a comprehensive and non-technical way the experience learned through the EveryAware project as a lens to gather the potential of the emerging frameworks of participatory sensing, citizen science, and social computation, coupled with the theoretical and modelling tools recently developed by physicists, mathematicians, and computer and social scientists to analyse, interpret, and visualise complex data sets. What is emerging is a very clear proof of concept about the potential ICT-mediated social sensing can have in monitoring and possibly affecting individual perceptions, the emergence of awareness, and the dynamics of opinions.

Before going into the details of the book content, let me summarise the context in which EveryAware moved and what has been achieved.

The Context

Our societies are being transformed by the pervasive role technology is playing on our culture and everyday life, in a so deeply way that many refer to this phenomenon as the third industrial revolution (Rifkin 2011, 2014). Techno-social systems is the locution more and more adopted to quickly refer to social systems (Vespignani 2009) in which technology entangles, in an original and unpredictable way, cognitive, behavioural, and social aspects of human beings. Technology helps connecting people and circulating information and affects more and more the way humans interact with each other. Every day, a huge amount of information is exchanged by people through posts and comments online, tweets or emails, or phone calls as a natural aptitude of humans to share news, thoughts, feelings, or experiences. This revolution does not come without a cost, and in our complex world always new global challenges emerge that call for new paradigms and original thinking to be faced: climate change, global financial crises, global pandemics, growth of cities, urbanisation, and migration patterns (Batty 2008, 2013; Gore 2007; Randers et al. 2004; Stern 2007).

The issue of sustainability is now on top of the political and societal agenda and is considered to be of extreme importance and urgency. We already have overwhelming evidence that the current organisation of our economies and societies is seriously damaging (Revkin 2011) biological ecosystems and human living conditions in the very short term (Ancona et al. 2015; Beelen et al. 2015; Eeftens et al. 2012; Peterson et al. 2015; Sunyer et al. 2015; Zhao et al. 2015), with potentially catastrophic effects in the long term (Climate Change Evidence & Causes 2014; Haines and Parry 1993; The Arctic in the Anthropocene 2014; Williams et al. 2015). A recent report from WHO (2014) states that in 2012 7 million people died—one in eight of total global deaths as a result of air pollution exposure, confirming that air pollution is now the world's largest single environmental health risk (Burnett et al. 2014).

Yet, there is generally not sufficient awareness to foster a rapid and effective change in behaviour and habits. If we look at the past policies, we observe a growing debate about several environmental issues and an emerging consensus about the need for a reorganisation of our most impacting daily activities—energy consumption, transport, housing, etc.—towards a more efficient and sustainable development mode. Unfortunately, the achievement of such a goal has been undermined by the difficulty of matching global/societal needs and individual needs (Hardin 1968; Ostrom 1990; Ostrom et al. 1994): still is the cumulative sum of people's individual actions to have an impact both on the local environment (e.g. local air or water quality, noise disturbance, local biodiversity, etc.) and at the global level (e.g. climate change, use of resources, etc.). Only filling this gap, by empowering people with new tools to assess the status of their environment and become aware of their living conditions and their future consequences, can make 'the environmental revolution' possible.

Public participation in environmental decision-making was pushed to the fore as a result of the 1992 Rio Declaration on Environment and Development. However, the provision and production of environmental information, particularly on issues such as noise pollution and air quality, rely heavily on a 'top-down' approach in which public authorities collect the data and release it to the public. There is still room to develop better mechanisms that support citizens to not only consume but to generate their own environmental information. If successful, such processes could lead to an increased awareness and learning about current environmental issues. Furthermore, this may serve to encourage more citizens to participate in environmental decision-making and ultimately stimulate them to take steps to improve their own environment based on new observation techniques.

The EveryAware project responded to this societal need by pushing the evolution of ICT with the aim of supporting informed action at the hyperlocal scale, providing capabilities for environmental monitoring, data aggregation, and information presentation. The goal was that of enhancing knowledge, understanding, and social awareness about environmental issues emerging in urban habitats through the use of ICT tools deployed to gather user-generated and user-mediated information from mobile sensing devices. To this end EveryAware exploited recent progress in Information and Communication Technologies (ICT) that have the potential to trigger the much needed transition towards a sustainable society. In particular:

- *ICT for Participatory Sensing*. Nowadays, low-cost sensing technologies are being developed to allow citizens to directly assess the state of the environment; social networking tools allow effective data and opinion collection and real-time information sharing processes. Through the use of ICT tools deployed to gather user-generated and user-mediated information from web-based and mobile sensing devices, the knowledge, social awareness, and understanding of environmental issues and living conditions in urban habitats will be enhanced. The possibility to access to digital fingerprints of individuals is opening tremendous avenues for an unprecedented monitoring at a 'microscopic level' of collective phenomena involving human beings. We are thus moving very fast towards a sort of a tomography of our societies, with a key contribution of people acting as data gathering 'sensors'. Interestingly, this participatory sensing also presents challenges regarding quality and cost of sensors, reliability and representativeness of collected data, widespread and enduring participation, as well as privacy. Participatory sensing data will have to be integrated with pre-existing information. New models of interaction between citizens, authorities, and scientists will have to be developed. In addition, the innovative integration of mobile technology, sensors, and socially aware ICT can contribute to a shift towards a green and sustainable economy, which has been seen by many policy makers as one of the exit strategies from the current financial and economic crisis.
- *Web-Gaming, Social Computing, and Internet-Mediated Collaboration*. In the last few years, the Web has been progressively acquiring the status of an infrastructure for social computing that allows researchers to coordinate the cognitive abilities of users in online communities and to suggest how to steer the collective action towards predefined goals. This general trend is also triggering the adoption of Web-games as a very interesting laboratory to run experiments in the social sciences and whenever the peculiar human computation abilities are crucially required for research purposes. There is a wide range of potential areas of interests going from opinion and language dynamics to decision-making, game-theory, geography, human mobility, economics, psychology, etc. For instance, spatial games (related to traffic, mobility, coordination, etc.) are aimed at investigating how people (from literate to non-literate) explore geographical

spaces and use geographical information in a way that is meaningful and culturally appropriate for them. Specific tasks can include coordination, exploration, cooperation, and annotation. At the same time, these games/experiments would allow the collection of sensible information about how people perceive their environment, e.g. by evaluating which scale and level of details in imagery is most meaningful. This information can be organised in layers, e.g. traffic or pollution in urban environments, social interest, landmarks, etc., and made available through suitable interactive visualisation tools in order to help people to understand environmental changes, so to facilitate informed decision-making. Along the same lines, the citizen games share the common denominator of the management of the commons as well as the monitoring of the environmental changes. Interesting activities here include the development of new tools for the sustainable management of natural resources (in particular for marginalised communities), a more aware use of them, good practices for recycling, food management, mobility, energy consumption, communication, etc.
- *Collective Awareness and Decision-Making*. The access to both personal and community data, collected by users, processed with suitable analysis tools, and represented in an appropriate format by usable communication interfaces, has the potential of triggering a bottom-up improvement of collective social strategies. By providing personally and locally relevant information to citizens, i.e. related to their immediate locality rather than to the city or region in which they live as a whole, one can hope to stimulate fundamental shifts in public opinion with subsequent changes in individual behaviour and pressure on policy makers. Enabling this level of transparency critically allows an effective communication of desirable environmental strategies to the general public and to institutional agencies. For instance, fostering awareness and improving environmental monitoring could contribute to the reduction of pollution and waste of energy or the improvement of biodiversity in urban areas. Fostering the birth of environmentally positive communities, stimulating bottom-up participation, and collecting public opinions and perceptions in a trusted way are all factors that will empower the general public and policy makers with tools to gauge and orient the democratic processes of decision-making.

In this framework, EveryAware deployed the infrastructures to support participatory sensing in an environmental framework, high-performance data gathering, and storage. The resulting EveryAware platform is highly effective and represented the main backbone for all the EveryAware activities. The very same realisation of the EveryAware infrastructure represents a major achievement of the project since for the first time we demonstrated a complete end-to-end infrastructure able to integrate participatory sensing, accuracy of measurements from low-cost sensors, people engagement, and mobile and Web technologies. This infrastructure has been successfully deployed in several case studies (cs.everyaware.eu) devoted to noise pollution (Becker et al. 2013) and Air-quality (Sirbu et al. 2015). In addition EveryAware launched the Experimental Tribe platform (Caminiti et al. 2013) (www.xtribe.eu), a general-purpose platform designed for scientific gaming and social computation whose aim is that of providing the scientific community with a tool to realise Web-based experiments by skipping all the unnecessary technical coding overhead. Finally, a great deal of attention has been devoted to the theoretical investigation of the social dynamics underlying the processes through which opinions are formed and individuals enhance their awareness.

Summary Description of the Project Context and Objectives

The EveryAware project expected to contribute significantly to the social goals of achieving greater awareness of localised, personalised environmental information through the implementation of novel infrastructures for bi-directional communication.

Specifically, it aimed to develop the tools and the knowledge needed to make environmental information transparent, available, and easily integrated with the perceptions of people, regarded as a first-order observable. *Bridging the gap between opinions and sensor data is the single factor that can make environmental knowledge actionable at the grassroots level.* Current approaches to the onset of sustainable practices in citizens' environmental behaviour have been based on top-down strategies for understanding behaviour (Jackson 2005) and have met with mixed success (Collins et al. 2003). The participation of citizens has traditionally been limited to opinion polls and public discussions where people have been asked to convey their needs and their opinions to panels of designated experts responsible for tackling emerging issues. The environmental monitoring activity, the public dissemination and discussion, and the policy making are performed in separate places and at different times, with little transparency about how environmental issues are treated by each actor throughout the whole process.

EveryAware project, conversely, has been based on the idea that citizens should be involved not only as passive receivers of pre-packaged environmental information, but also as active producers of it, by means of the networking possibilities allowed by mobile devices, pervasive Internet access, Web 2.0, and the mobile Web tools that support sharing and annotations of geo-localised content. The framework envisioned in the project allows users to participate in all stages of environment management: by contributing to enrich its monitoring, expressing opinions, joining a motivated community, and eventually implementing best practices with the potential to improve environmental conditions.

The notion of geo-localised user-generated content is of course not novel. A number of participatory websites and Internet-based scientific projects have been successfully deployed (see Goodchild (2007), Flanagin and Metzger (2008), and Hudson-Smith et al. (2009) or http://tah.openstreetmap.org for examples and a review of the field of Volunteered Geographic Information). However, most collaborative Web-based systems have bound themselves to merely visualise the data collected by users, without a scientific analysis of it. In contrast, EveryAware proposed that users participate in the scientific endeavour itself by making use of current and emerging hand-held electronic devices incorporating significant computing power. Such devices should be easily connected to sensing equipment and to the Internet without requiring specific expertise from the user. In the field of environmental monitoring and research, it was, and still is, a great novelty to deal with data from a large number of mobile, randomly distributed, ‘uncontrolled’, low-cost, and therefore potentially less reliable sensors carried by nonskilled individuals, as compared to the practice of a limited number of mostly stationary and highly controlled data collection systems based on expensive high-quality measurement instruments. It was additionally novel to involve non-expert users in an end-to-end process from data capture to final output. The integration of participatory sensing with the monitoring of subjective opinions has been the key and crucial novelty of EveryAware, as it has the potential to expose the mechanisms by which the local perception of an environmental issue, corroborated by quantitative data, evolves into socially shared opinions and how the latter, eventually, drive behavioural changes. In our opinion, this approach represents a scientific and technological advance from several points of view as explained below, and EveryAware carefully addressed all the different research and technological challenges it implies. In the following, we briefly describe them.

The EveryAware Platform A key technological novelty of the EveryAware project has been the design and the implementation of the so-called EveryAware platform that handles both sensor and subjective data acquisition. The platform is a modular system composed by several components: a SensorBox to gather objective data about the environment, a smartphone controlling the data acquisition and the user experience, a system of data gathering, storage, analysis, and visualisation, and several Web-services. This approach guarantees high scalability of the overall system and allows for further developments aimed at having pluggable sensors, eventually miniaturised and integrated (e.g. wearable sensors). At the same time, the associated software platforms allow users to easily upload their sensor readings and equally easily tag these with subjective information. The ICT challenge here was that of making this upload process as automatic and natural for the user as possible.

Community Engagement Work dating as far back as 1969 (Arnstein 1969) lists the possible levels of citizens’ participation, ranging from non-participation to citizen control (where budgets are assigned to the citizens themselves) and more recent projects (Aoki et al. 2009; Haklay and Whitaker 2008; Maisonneuve 2008; Paulos et al. 2007; The Digital Geographers 2009) stress the importance of the participation process and the impact that informed community members have on local decisions. Such participation can improve both the science literacy of a population (Paulos et al. 2009) and offer different views of communities (Srivastava et al. 2006) to scientists: the real-time monitoring of opinions related to empirical observations will provide environmental sociologists with a corpus of detailed knowledge about how environmental conditions are perceived by a community: What issues are regarded as most relevant? How are novel behaviours propagated? What motivates participation, engagement, and behaviour change? Motivation for users' engagement and continuing participation in online project such as Wikipedia (http://www.wikipedia.org/) or OpenStreetMap (http://www.openstreetmap.org/) has already been extensively examined (Benkler 2002; Haklay et al. 2007; Nov 2007). However, similar motivations cannot necessarily be attributed to the citizen sensing participants in the EveryAware project, which presumably requires a higher level of commitment to that of a Wikipedian (who contributes 8.27 h per week on average (Nov 2007). Obtaining information related to encouraging initial and continued participation was therefore fundamental to the developers of systems such as EveryAware as it can be utilised to ensure that participants are highly motivated to engage with the project and more importantly remain engaged over the longer term. Novel research has been focused on two aspects of the problem. Firstly, a number of participant recruitment techniques (such as social networking sites, flyers, posters, e-mail campaigns) have been trialled systematically to identify those that achieve greatest success and validate whether similar techniques can be applied both in cross-border situations and with groups having different interests. Secondly, still ongoing research is identifying a list of motivations for ongoing participation once recruited, with a particular focus on those users who remain engaged with the project over a longer term. The results from both elements of research not only informed all the stages of the project but will also be of great relevance to similar participatory projects elsewhere.

Processing Sensor Data Specific issues emerged concerning sensor data. To illustrate this point, let us focus on air quality sensors. Although in most epidemiological studies air quality is commonly defined at the level of a city, recent air quality studies have highlighted that significant differences in pollutant concentrations, and in related health effects, can occur over the day and between different locations (Beckx et al. 2009; Kaur et al. 2007; Milton and Steed 2007; Wilson et al. 2005). The measurement of air quality at a high spatial and temporal resolution can yield a tremendous advance in the characterisation of the pollutants' urban concentration variability. Measuring mobility and activity patterns allows researchers to gauge the real-world exposure of citizens and in turn the overall effect on the health of urban communities.

The use of networks of available low-cost sensors will enlarge the data coverage. In the past, the adoption of low-cost sensors for ambient air quality monitoring has always been constrained by lack of accuracy, selectivity, and reliability (Carotta et al. 2007). However, new sensing technologies (arising from additional developments in the fields of semiconductors, nanotechnologies, and fibre optics, amongst others) will bring the detection limits of commercial sensors to the part-per-billion range needed for air quality monitoring. At the same time selectivity increases (Brunet et al. 2008; Elmi et al. 2008; Li et al. 2003; Viricellea et al. 2006). Thanks to the integration of cheap sensors in sensor networks, increased data availability, network intelligence, and advanced data mining techniques, limited accuracy and reliability can further be countered (Kularatna and Sudantha 2008; Ma et al. 2008; Tsujitaa et al. 2005) (see also IDEA project http://www.idea-project.be).

Several research projects have developed or are developing low-cost portable air quality sensing tools based on commercially available sensors (Aoki et al. 2008; Eisenman et al. 2007; Honicky et al. 2008; Hull et al. 2006; Maisonneuve et al. 2009; Milton and Steed 2007; Völgyesi et al. 2008) (see also http://www.lamontreverte.org/, the Cambridge Mobile Urban Sensing (CamMobSens) http://www.escience.cam.ac.uk/mobiledata/ or http://urban.cens.ucla.edu/projects/cyclesense/). However, when EveryAware started, none of those efforts had reported extensive field trials or reported full-scale validation exercises. Specific technical challenges have also to be tackled such as the precision of GPS in densely built urban environments (Milton and Steed 2007).

Combining Sensor and Subjective Data One of the main novelties of EveryAware has been the strong effort towards an integration of sensor and subjective data in order to provide insights about the social perception of the state of the environment (see also below). A quantitative analysis of the gap between perceived and measured environment had never been attempted in a systematic way. Both kinds of data are affected by the procedures to gather them as well by intrinsic biases, both in space and in time. This raised new issues of data validation, calibration, interpretation, and representativeness that had to be tackled in a creative way and embedded in digital data-processing procedures in an, as much as possible, autonomous, learning way.

Citizen Science An important challenge concerns the development of and examination of the use of Web-based tools through which (groups of) interested lay people and scientific experts can interact directly, discuss provisional results of data collection, and mutually enrich both the data itself and the interpretation of the data. Here the actual challenge was the presentation of complex scientific analysis in a user-friendly manner to non-specialists. From this point of view, the project paid a special attention to ICT challenges that include (i) the usability of the interface design so that users can easily find the desired information (at the individual level or aggregated) (ii) the appropriateness of the actual displaying methods: how to present results so that non-specialist users understand both the analysis undertaken and the outcomes? Will access to this information help users feel rewarded and part of a community, encouraging further participation? Thus, the overall novelty of this component of the project has the development of a user-friendly manner to present complex scientific analysis (both the methods and the results) to non-specialists.

Opinions and Behavioural Change The direct involvement of the users in the research as described above leads to the potential discovery of emerging behavioural patterns, as well as to an assessment of the impact of new technological solutions at the socio-economic level. Despite these benefits, none of the existing studies (Aoki et al. 2008, 2009; Eisenman et al. 2007; Honicky et al. 2008; Hull et al. 2006; Ma et al. 2008; Maisonneuve et al. 2009; Milton and Steed 2007; Paulos et al. 2007) (see also http://www.escience.cam.ac.uk/mobiledata/ or http://urban.cens.ucla.edu/projects/cyclesense/) using citizen sensors specifically evaluate individual behaviour change in any way, although Honicky et al. (2008) and Milton and Steed (2007) raise this as an issue to be investigated.

This issue is closely linked with the concept of participant motivation described above—will a participant sufficiently engaged with the project also modify his or her behaviour as a result of the personalised information presented? Lawrence (2009) notes that the link between engagement and behaviour change is not yet fully established in the context of environmental change and climate change discourse. Although other studies using diverse sources of data have identified the usefulness of such individualised information (Darby 2008; Paulos et al. 2007), many of the citizen sensor studies are still at pilot stage (Honicky et al. 2008; Milton and Steed 2007) and do not state behavioural investigation as one of their direct aims.

In general, the dynamic processes underlying the formation and the evolution of opinions, uses, and behaviours have rarely been investigated in experimental settings and almost never coupled to the exposure of users to suitably detected and processed relevant information. Influencing behaviour change is notoriously difficult due to the complexity and variety of factors that affect behaviour (Jackson 2005), and a number of alternative models have been proposed. 'Expectancy-value' theories group together model whose choice is motivated by the expectations we have about the consequences of our behaviour and the values we attach to those decisions (Jackson 2005) (e.g. the rational choice model). Staged models (Prochaska and DiClemente 1986 and Lee and Owen (1985) (State Government of Victoria 2006)) include the fact that understanding and assimilation of the consequences of an action may be incomplete, that information may relate to events in the future (e.g. the possibility of developing lung cancer), and that a distinct cognitive effort is required to modify behaviour (Jackson 2005). The basis of all behaviour models, however, is the assumption that knowledge and awareness of an issue or a problem are key requirements for a behavioural change. However, very few studies have been undertaken on changes in individual behaviour due to the provision of individual-specific information.

A theoretical contribution to the understanding of opinion and behaviour change came from recent studies performed in the opinion dynamics field (Castellano et al. 2009). Such interdisciplinary area focuses on the modelisation of opinion spreading in large social networks, with a heavy use of mathematical tools and methods borrowed from statistical physics. Many models have been developed in the literature to explain how social systems develop a consensus on a given issue (e.g. on political votes) or which social interaction favours the coexistence of multiple opinions in a community (Lambiotte and Ausloos 2007; Sznajd-Weron and Sznajd 2000). However, empirical bases behind such models are still scarce, in particular for what concerns the opinion dynamics, which requires the monitoring of a social system during time. Although some of the partners had already explored these problems in recent works, focussing on the emergence of semantic agreement in social networks (TAGora 2007), crucial issues such as the study and the modelisation of the resistance to opinion shift are still a largely unexplored field. The EveryAware project contributed to provide the empirical, computational, and theoretical basis for an advance in such line of research.

Book Structure

The book will cover the above-mentioned themes in a series of chapters organised in the following three main parts.

Part I *New Sensing Technologies for Societies and Environment* (coordinated by: Andreas Hotho, Gerd Stumme and Jan Theunis). Part I presents an overview of novel ICT-based or ICT-mediated concepts, tools, and methods in data collection/monitoring using both technological and human sensors. It describes the technological potential and challenges/boundaries of these sensing opportunities to observe the environment, people's activities, and subjective elements such as opinions, interpretations, and moods. It also describes issues related to data ownership and privacy.

Part II *Citizen Science, Participatory Sensing, and Social Computation* (coordinated by: Muki Haklay and Vito D.P. Servedio). This part discusses concrete case studies where the tools described in Part I have been successfully deployed to monitor the social processes behind the emergence of awareness.

Part III *Collective Awareness, Learning and Decision-Making* (coordinated by: Vittorio Loreto and Francesca Tria). Finally, Part III gives an overview of different studies and approaches that have been pursued with the aim of gaining a deeper insight into the mechanisms that drive people's understanding of environmental issues and enhance their awareness with the final goal of elucidating under which conditions it is possible to foster an effective change towards more virtuous behaviours.

Each part includes a series of contributions not only from scholars who took part to the project but also from experts in their own respective fields, and it will be opened by a short introduction that summarises the main themes and put the different contributions in the right perspective. I hope this will provide the audience with a comprehensive picture of the state of the art along with hints about the roadmap in front of us. Have a nice trip.

Now it is time for the acknowledgements. First of all, I wish to thank all my coeditors and colleagues for the constant support both during the project's lifetime and the preparation of this book. Also on their behalf, I wish to thank all the contributors who gracefully accepted to submit their papers for this volume and made a strong effort to keep the deadlines. Also many thanks to all the friends and colleagues who helped us in reviewing the book's contributions and make the whole book a consistent piece of work. Finally, I wish to thank all the junior and senior scientists and administrative and scientific secretaries who made an especially egregious job in keeping together all the different threads the project generated and put their enthusiasm at the service of the whole Consortium. Last, but not least, I wish to

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Rome, Italy/Turin, Italy/Paris, France Vittorio Loreto
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Contents

Part I
New Sensing Technologies for Societies and Environment

Introduction

New ICT-Mediated Sensing Opportunities

Andreas Hotho, Gerd Stumme, and Jan Theunis

During the last century, the application of sensors has emerged in a large variety of domains: industrial processes are controlled by sensors measuring temperatures, pressures, filling levels and flow rates; weather stations measure wind speed and direction, air temperature, humidity, and rain-gauge; and induction loops measure road traffic.

With increasing network coverage and decreasing sensor sizes and production costs, this technology has become broadly available for interested citizens. This includes not only simple sensors like temperature but also more advanced ones, e.g., sensors for gas or radiation. These days, for instance, semi-professional weather stations are available in most hardware stores, and everyone can contribute to networks such as wetter.com,[1] which are used for weather forecasts.

With the rise of mobile applications (in particular GPS and smartphones), spatial coverage has increased. Interested citizens have started with systematic observations of their environment. Probably the most prominent and successful example is the creation of OpenStreetMap,[2] a map generated by two million people using the

[1] http://www.wetter.com/wetter_aktuell/wetternetzwerk/.

[2] http://www.openstreetmap.org.

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Global Positioning System (GPS). In many locations, its coverage already surpasses commercial online maps such as Google Maps or Bing.[3]

With every new generation, smartphones come along with an extended list of sensors. Today, almost every smartphone is equipped with a microphone, a camera, GPS, an accelerometer and a gyroscope. The different connectivity modes of a phone (GSM, WiFi, bluetooth) can also serve as sensors, as they are able to determine both the location of the device and the proximity of other devices. Additionally, smartphones can be extended by external sensors, for instance for measuring radioactivity or air pollution in the environment, but also for observing the biological state of the user (e.g. step counter, heart rate, sleeping state).

New smartphone generations do not only contain new sensors but also bring advanced connectivity features. Nearly everywhere in the world devices can connect to the internet and, thus, can send and receive information. This connectivity can be used to advance the process of collecting sensor measurements on a central server and allows to directly collect user feedback. It plays a central part in the upcoming process of a ubiquitous collection of distributed information and is the basis of a new way of sensing.

The combination of novel sensing technologies, developments in ICT, new ways of information collection and intelligent data processing techniques leads to new concepts of decentralised and widespread data collection by non-experts, often described as human sensing, participatory sensing, urban sensing, crowdsourcing or citizen science. Their common thread is that new opportunities arise to collect and analyse novel data to understand the world surrounding us with increasing involvement of the general public in the process. In the following we will shortly introduce the main concepts and some characteristics of collective sensing.

Part I of this book deals with these new sensing technologies for societies and environment, and focuses on their technological possibilities and constraints. The term *sensing* can relate to *sensor*. According to the Oxford English Dictionary a sensor is *a device which detects or measures a physical property and records, indicates, or otherwise responds to it*. But it can also relate to *sense* which is defined as *a faculty by which the body perceives an external stimulus*, referring in the first place to the traditional senses sight, hearing, taste, smell and touch. Both sensors and senses detect physicochemical properties of the environment. However, in an extended meaning *sensing* also relates to the psychosocial environment, such as in sensing danger, sensing tension in a group of people or sensing someone's mood. In this meaning sensing refers to a higher level of integration and interpretation of different external and internal signals.

In a similar manner we will use *sensing* to refer to detecting and recording signals that contain information on people's physical, natural and social environment. This includes both physicochemical signals, such as sound, radiation or images, and psychosocial signals such as behavior, opinions or moods. We define *sensing* as collecting observations relating both to facts (objective) and to interpretations,

[3] http://sautter.com/map/ allows for directly comparing both maps.

opinions and moods (subjective) with the help of a sensor. Thus, we extend the definition of a *sensor* to include *technological sensors* as well as *human sensors* both reflected and discussed in this part.

The above-mentioned definition of a *technological sensor* refers to a *device* capturing physicochemical signals and translating them in a meaningful value, such as a microphone translating a pressure into a noise level or a gas sensor translating a change in resistance into a gas concentration.

Nowadays, however, the tremendous technological development in data communication, data storage and computing power allows to generate and analyse streams of tags, comments, votes, ratings, opinions or counts. Thus, we also define *human sensors* as the tools used to collect and extract meaning and information on the physical, natural or social environment from information registered by humans through text, numerical values or categories without the use of technological sensors. This information can relate to objective facts, such as a count of the number of birds that passed by, or a tag specifying that a sound is produced by an idling car, or it can relate to subjective impressions, opinions and moods. Note, that while human sensors can capture direct reports of such subjective information, they can also make use of tracks that are left inadvertently, e.g. in twitter feeds or web search activities.

Novel types of sensing data can be collected in a purpose-oriented way with dedicated sensors such as air quality sensors, an app recording noise levels or a camera providing pictures. Purpose-oriented data collection can make use of *targeted* data collection campaigns in which data are collected along specified lines according to a specific goal. This will in most cases need active and conscious participation from the person collecting the data. In *opportunistic* data collection campaigns, people are collecting data during their normal daily routines without any specific guidelines.

But data that is initially intended for one purpose, can also be re-used or exploited for a purpose that is entirely different from the initial context, e.g. twitter feeds can be used to extract mood information, local environmental measurements from different sources can be mashed up to extract broader patterns, internet query logs can be used to extract information on spread of disease and GPS data from car navigation systems can be used to extract information on traffic speed, congestion and travel times. In all these cases data are sourced from available data stores, and data and text mining techniques are used to derive meaning from the data.

The different chapters of Part I of this book give an overview of the state-of-the-art in different sensing domains and sensing technologies, and illustrate their potential as well as the challenges with examples. They deal with sensing systems that can be used actively (possibly with some training) by the general public, or to which the general public contributes by leaving their data (knowingly or unknowingly), and as such create new opportunities for collecting novel data, improving monitoring, and understanding the environment, human behavior, opinions and moods.

In Chap. 1 “Human Sensors on the Move” D. Ferreira, V. Kostakos, and I. Schweizer highlight the opportunities created by the omnipresence of mobile phones to generate information on several aspects such as human mobility (based on bluetooth, WiFi, GPS), air pollution (based on gas sensors), and noise. Smartphones are turned into information gatekeepers making intelligent inferences about what its sensors capture and providing information when needed. The authors discuss the practical problems that have to be addressed to turn a smartphone in a truly mobile sensing device. Smartphone embedded sensors are cheap and generally of low quality, and they need calibration. Another crucial issue is the high energy consumption for continuous sensing. Finally, the authors present middleware frameworks that allow for easier development of sensor applications on top of smartphones.

In Chap. 2 “Sensing the Environment”, J. Theunis, M. Stevens, and D. Botteldooren specifically address the prospects for *environmental sensing* with technological sensors. New sensors and apps create opportunities for more detailed environmental monitoring, as compared to official monitoring networks, and for involving the general public through participatory data collection and monitoring schemes. However, proper monitoring often requires important efforts in developing and validating sensing devices and in processing the collected data. The authors illustrate this with two environmental parameters that recently received a lot of interest, air quality and sound, and discuss the possible added value, the technical challenges and future prospects in these domains. Low-cost sensors have to be optimised for environmental monitoring which involves know-how on sensing technology, electronics, software development and data processing, as well as a thorough knowledge of the dynamics of the parameters that are monitored. They also point out that features, such as air quality or noise, can be highly variable both in space and time. The spatial and temporal resolution of such measurements has to be in line with this variability.

Besides environmental monitoring the increasing presence and use of technological sensors such as GPS or RFID, (or radio signals used for communication such as Bluetooth or WiFi) in daily life leads to new opportunities to track and analyse *human behavior*. In Chap. 3 “Observing Human Activity through Sensing”, S. Gautama, M. Atzmueller, V. Kostakos, D. Gillis discuss how human mobility patterns can be detected, ranging from traffic control by induction loops and manual counting (e.g. for car occupancy rates) over camera networks to bluetooth scanning of pedestrians and users of public and private transport. In a set of case studies, Chap. 3 shows how floating car data are used for the monitoring of traffic flow, how smartphone data are used for the monitoring of dynamic, multimodal crowd behavior, and how WiFi signals are exploited for analysing tourist mobility patterns in a city.

A complementary perspective on the relationship between users and sensors is taken by V. Kostakos, J. Rogstadius, D. Ferreira, S. Hosio, and J. Goncalves analyse in Chap. 4 “Human Sensors”. They discuss how humans are not only the target of sensing activities, but also take over the role of the sensors themselves. The authors focus on three domains: collecting human contributions through crowdsourcing platforms, data mining of online social media (in particular for crisis response), and the collection of data and opinions in urban and in-situ systems that collect data from pedestrians.

Privacy, trust management and incentives for participation are important issues for participatory sensing applications. These issues and their dependencies are discussed by Mehdi Riahi, Rameez Rahman, and Karl Aberer in Chap. 5 "Privacy, Trust and Incentives in Participatory Sensing". As an example, anonymising the collected data will improve the users' privacy, but will make trust management more difficult.

Collecting sensor information together with user input is one of the key factors to allow for a proper analysis of the data. Challenges like storing, visualizing and analyzing data addressed in web-based platforms are the topic of Chap. 6 "Collective Sensing Platforms" Martin Atzmueller, Martin Becker and Juergen Mueller. As the amount of data is increasing rapidly, issues like big data processing and sensor cloud storage are becoming more and more important which is also reflected in the platform design. In addition to this, the technological challenges are discussed resulting from the full cycle of collecting data with smartphones to processing and visualizing them on a web system.

The last chapter of this part is "Applications for Environmental Sensing in EveryAware" by Martin Atzmueller, Martin Becker, Andrea Molino, Juergen Mueller, Jan Peters, and Alina Sirbu. It focuses on the technical basis of the EveryAware platform. Two example applications, namely AirProbe for measuring air quality and WideNoise for recording noise pollution are introduced. Beside the challenges of AirProbe specific sensing hardware and the WideNoise smartphone based sensing technology, the focus of this chapter is on the features of the web server component. Specific features like real-time tracking, data storage, analysis and visualizations are discussed along with the two applications.

With this application specific chapter we conclude this part of the book about new ICT-mediated sensing opportunities. With further advances of sensing and processing technology, we envision another big step in this area towards more detailed insights into our environment. The combination of objective sensor measurements and subjective impressions of users are two sides of the same coin and will lead to new ways of understanding the current environmental situation in our daily life.

Chapter 1
Human Sensors on the Move

Denzil Ferreira, Vassilis Kostakos, and Immanuel Schweizer

1.1 Human Sensors on the Move

In this section we provide an extensive summary of *human sensors on the move*, or mobile systems that are designed to collect data from smartphones that users carry in their everyday life. One can rely on people's own mobile phones to collect data as they are at their close vicinity 90 % of the time (Dey et al. 2011). These devices have immense potential to collect rich data about people's behaviour and habits, as well as their environment. In this chapter, we first outline the general idea of human sensor, then dive into some technical challenge before we present a number of systems to generate context on mobile phones.

1.2 Movement Generates Information

Mobility has received a lot of attention as a defining feature of the move from desktop-bound computing to pervasive computing. Strongly linked to mobility is the notion of encounter. The movement of people and devices through an urban environment brings them into contact with each other. In an urban pervasive computing system, there are additional patterns of encounter between diverse combinations of users, places, mobile devices, fixed devices, and services. This results in an

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enormously increased number of spontaneous interactions with consequent effects on security and privacy (Kindberg and Zhang 2003).

A number of projects have focused on capturing mobility data enabled by the popularisation of mobile and wireless technologies. For example, the Reality Mining project (Eagle and Pentland 2006) collected proximity, location and activity information, with proximity nodes being discovered through periodic Bluetooth scans and location information by cell tower IDs. Several other groups have performed similar studies. Most of these use Bluetooth to measure mobility (Balazinska and Castro 2003; Kostakos et al. 2010; Nicolai et al. 2006; Perttunen et al. 2014), while others rely on WiFi (Chaintreau et al. 2007; McNett and Voelker 2005). The duration of such studies varies from 2 days to over 100 days, and the numbers of participants vary from 8 to over 5000. The BikeNet project (Eisenman et al. 2010) explored the use of people-centric sensing with personal consumer-oriented sensing applications and sensor-enabled mobile phone applications, which can potentially enable applications such as noise mapping and pollution mapping. The Pervasive Mobile Environmental Sensor Grids (MESSAGE) project aimed to collect data at a metropolitan scale through smart phones carried by cyclists, cars, and pedestrians monitoring carbon dioxide values, with an ultimate goal of controlling traffic in the city of Cambridge. Similarly, the urban sensing project CENS (Burke et al. 2006) sought to develop cultural and technological approaches for using embedded and mobile sensing to invigorate public space and enhance civic life.

1.3 Smartphones as Information Gatekeepers

Mobile phones have become miniaturized computers that fit in a pocket. They are inherently *personal* and their potential to sense the user's environment, i.e., context, is appealing to researchers. The *convenience* and *availability* of mobile phones and *application stores* makes it easier for a researcher to reach *thousands* of users. More importantly, mobile phones have several built-in sensors (e.g., accelerometer, gyroscope). Primarily used to enhance the user experience, such as application functionality or mobile phone user interaction (e.g., vibration feedback, screen orientation detection), these sensors are increasingly being leveraged for research purposes.

For example, mobile phones have been used to understand population movement flows in a city (O'Neill et al. 2006), and the Reality Mining team led the way on user-focused data collection via mobile phones (Eagle and Pentland 2006). O'Neill et al. (2006) abstracted a city into a graph thus proposing a conceptual framework for designing and analysing pervasive systems for urban environments (Kostakos et al. 2006). This necessitates the ability to *detect*, *infer* and *predict* *individual* and *collective* users' needs. Paraphrasing Weiser (1999), the twenty-first century computer is a non-centralized, distributed computer amongst multiple devices, working together to sense the world. It is a computer that disappears and makes intelligent inferences about what its sensors capture and provides information when one needs it. Mobile phones are currently the most widespread sensing device. Widespread, mobile instrumentation promises research opportunities and facilitates a better understanding of human behaviour.

However, challenges inherent to mobile computing such as *heterogeneity*, *transparency*, *security*, to name only a few, require a *collaborative* research effort to manage user's context.

The next two sections are dedicated to the open challenges of *sensor calibration* and *energy consumption*. These challenges are inherent to all wireless sensor devices. But they are amplified by the scale of deployments and the mobility envisioned with smartphones.

1.4 Calibrating Smartphones

As highlighted last section, smartphones are the perfect sensing device. They provide powerful hardware, with new sensors built in with every hardware iteration. However, these sensors are cheap and generally of low quality. They are not built in to deliver high quality context on the move. Hence, a number of researchers have tackled the challenge of how to calibrate smartphones in the past. Calibration is a challenge most prevalent for physical sensors, e.g., the microphone. The microphone is a good example as it is often used by researchers to measure sound pressure levels. Combining these measurements creates powerful environmental maps. However, a smartphone microphone is meant to pick up voice, not measure sound pressure. There is no wind cancelation and some frequency are suppressed, while others are increased. This has led to a number of algorithms trying to calibrate smartphone microphones. Simple approaches use a constant (Rana et al. 2010), while more sophisticated algorithms alter the measured frequencies before applying a calibration constant (Schweizer et al. 2011; D'Hondt et al. 2013).

While these algorithms work, they require manual effort for every smartphone calibrated. This is infeasible as the number of smartphones in existence is growing rapidly. A more promising approach has been introduced by Hasenfratz et al. (2012). They propose on-the-fly calibration (Hasenfratz et al. 2012). Here, smartphones are calibrated while passing calibrated stationary sensors.

Mobility and scale seem to increase the calibration challenge with calibration. However, mobility creates possible contacts between sensors, hence, using the mobility of the users to calibrate the device seems to be the only feasible solution given the amount of devices in question. This is still a basic, open question to human sensors on the move, dictating the data quality of the overall system. Assuming we can generate calibrated samples, the next sections discusses the possible impact of sensing on the energy consumption and the user.

1.5 Energy Consumption

Capturing the user's context, especially in high fidelity as discussed last section or for real-time use cases, requires high sampling rates and continuous sensing. However, applications with high power consumption see only limited success (Banerjee et al. 2007). Smartphones are expected to last through at least one working day. Over the past years a lot of research has gone into understanding and measuring power consumption. Power consumption on smartphones may be derived by either directly measuring the power consumption (Schweizer et al. 2014) or using device dependent power models in combination with the system utilization (Zhang et al. 2010). Nacci et al. (2013) extend this approach by proposing a framework allowing automatic power model generation. These are then used to suggest the user certain energy conserving actions.

The increasing number and use of sensors make them a major source of power consumption in modern smartphones. However, it is only through the use of those sensors that mobile sensing is a worthwhile endeavour (Lane et al. 2010; Khan et al. 2013).

Considering the power drain, continuous sensing is incredibly hard to achieve. In recent efforts researchers have started to work on more energy-efficient continuous context sensing algorithms, e.g., for location (Zhuang et al. 2010; Kim et al. 2010) or activity (Wang et al. 2009). Others have focused on optimizing the network power consumption as the second largest consumer after the display (Rathnayake et al. 2012).

Based on this works, Kansal et al. (2013) analyse the trade-off between sensing accuracy and the power consumption of the smartphone. They argue that a programmer building mobile context sensing applications should be able to specify two dimensions: (1) the *latency* at which context change is detected and (2) the *accuracy* of the inferred context.

They propose the latency, accuracy, and battery (LAB) abstraction to specify these dimensions. Their Senergy API is then supposed to provide the most energy-efficient context sensing algorithm to fulfil the specified requirements. This is a powerful approach lending app developers a tool to improve both programmer productivity and energy efficiency.

Calibration and energy efficiencies are basic challenges in the sense that they limit data quality and quantity one can achieve with human sensing. They are also in some sense limitations imposed by the hardware used today. The next section tackles the crucial first step in building a research ecosystem for mobile sensing: addressing the challenge of *reusability* of context. Researchers and application developers need *tools* to detect, manage and *reuse* context, from diverse sources without starting from scratch.

1.6 Smartphone Instrumentation

Human sensing is changing rapidly. Hence, there is an increasing number of researchers building their own system, capturing and processing context. Given the basic challenges in capturing and processing context, e.g., calibration and energy, these systems often duplicate effort. Hence, reusability is crucial to decrease the barrier into human sensing and allow for much faster and, at the same time, higher quality in conducted research. Given this requirement, we will introduce 17 mobile context framework and highlight their audience, the sensors available, the system architecture, and their flexibility.

The Context Toolkit (Dey et al. 2001) is the reference conceptual framework for developing context-aware applications. It separates the *acquisition* and *representation* of context from the *use* of context by a context-aware application. Since the Context Toolkit was introduced, ubiquitous computing has become increasingly mobile and so has the user's context. To address different mobile computing constraints and challenges, several research tools have been developed over the years, as follows in chronological order.

CORTEX (Biegel and Cahill 2004) allows researchers to fuse data from mobile sensors, represent application context and reason about context. *CORTEX* introduced the concept of a sentient object model for the development of context-aware applications. By combining sentient objects and an event-based communication protocol for ad-hoc wireless environments, *CORTEX* targeted mobile context-aware researchers to define inputs and outputs, contexts, fusion services and rules using an inference engine which followed an event-condition-action (ECA) execution model. Similarly, *Context Studio* (Korpipää et al. 2004) is a middleware that takes into account users' mediation and accountability in context inference, as it is challenging to fully automate actions based on context alone. Mediation of context-dependent actions was manual, semi-automated, and fully automated. *Context Studio* uses a blackboard approach (i.e., multiple sub-problems combined solve the problem) to create contextual rules, actions and triggers. Users could combine the existing contextual probes to add context-awareness to the mobile phone.

ContextPhone (Raento et al. 2005) is a widget-based mobile middleware. ContextPhone is built on top of four essential components: sensors; communications; widgets and system services. Available sensors probed location, user interaction, communication behaviour and physical environment. Fundamental to *ContextPhone* was the idea of context as an understandable resource for the users, in other words, context intelligibility. Using widgets, users had control over the sensors data collection. *AWARENESS* (van Sinderen et al. 2006) is a middleware that prioritizes users' privacy concerns. The middleware applies the concept of Quality of Context (QoC) to express the quality characteristics of the context information. Users' privacy concerns would increase or decrease QoC, depending on how much context is shared at any given time (e.g., disabling GPS would reduce the QoC for the context of location). Context is shared with previously trusted devices and the mobile phone user is the sole controller of privacy aspects. *AWARENESS* focused on mobile healthcare applications for patients and medical researchers.

Momento (Carter et al. 2007) was a middleware with integrated support for situated evaluation of ubiquitous computing applications. Momento's mobile client displayed questions to the user and was able to log location, nearby people and audio. The researcher had a desktop client to configure and oversee a remote deployment. *Momento* was integrated with the Context Toolkit (Dey et al. 2001) for fixed applications. For researchers, *Momento* leveraged existing devices as much as possible; provided support for multiple communication options; supported qualitative, quantitative and context data in a unified client system; supported monitoring and notifications; and supported lengthy and remote studies. The *MyExperience* (Froehlich et al. 2007) middleware captured both sensor- and human-based data to understand the user's motivation, perception and satisfaction on mobile technology. Human-based data collection (e.g., surveys and user experience sampling) was triggered off sensor readings and pre-established researcher's rules. *MyExperience* supported remote opportunistic synchronization of the collected mobile data and survey answers to a remote server, to ensure access to the data as soon as possible.

CenceMe (Miluzzo et al. 2008) middleware inferred physical social context and shared information through social network applications (e.g., Facebook and MySpace). *CenceMe* introduces a split-level classification approach for sharing social context. Social context detected locally on the device is transferred to a backend server to match common shared social contexts to raise social awareness. With the split-level classification approach, classification can be done on the phone with the support of the backend servers, or entirely on the phone. CenceMe focused on users' social experiences. *EmotionSense* (Rachuri et al. 2010) focused on social psychology context. The middleware could sense individual emotions, activities, and verbal as well as proximity interactions amongst friends. The middleware could detect speakers' identities, emotions and location. EmotionSense supported social scientists, allowing them to describe sensing tasks and rules to manage sensors according to the detected users' social context.

Empath (Emotional Monitoring for PATHology) (Dickerson et al. 2011) was a middleware to remotely monitor emotional health for depressive illness. *Empath* is composed of a set of integrated wireless sensors, a touch screen station and mobile phones. Patients' diagnosis and therapeutic treatment planning were supported by reports generated by aggregating context such as sleep, weight, activities of daily living, and speech prosody. The behaviour analysis routines run on the server and results would be displayed on the touch screen fixed station at patients' homes.

Funf (Friends and Family) (Aharony et al. 2011) middleware focused on social and behaviour sensing. Funf instruments the available hardware and software sensors on mobile phones (e.g., GPS, accelerometer, calls, messages, installed applications, running applications). Funf is for researchers interested in collecting social and behavioural data and studies. "Self-tracking" users can also use the Funf Journal application to collect their personal mobile data. *Ginger.io* (Ginger.io 2012) is a behavioural analytics middleware that turns mobile data into health insights. *Ginger.io* provides a web-based dashboard for healthcare researchers and providers and a mobile application for patients. The mobile application passively collects movement, call and texting patterns. In a daily or weekly basis, the mobile application requests feedback from the patients, as 3–5 steps questionnaires.

SystemSens (Falaki et al. 2011) middleware captures *usage context* of mobile phones. Usage context is the collection of users' interactions with research applications. The users' interactions include battery, call, CPU usage, cell location, data connection active and traffic and telephony information events. SystemSens is a researchers' middleware to instrument research applications and loggers. *Ohmage* (Ramanathan et al. 2012) is a mobile phone-to-web middleware designed to create and manage experience sampling based data collection campaigns in support of mobile health pilot studies. It supports time- and location-triggered self-reports; activity recognition based on sensor-fusion of accelerometer, GPS, Wi-Fi and cell tower radios; location tracking; exercise and sleep tracking; acoustic traces for social interaction detection; motivational messages for participant engagement. *ODK* (Open Data Kit) *Sensors* (Brunette et al. 2012) is a middleware to simplify the interface between external sensors and mobile phones. *ODK Sensors* abstracts application and driver development from user applications and device drivers, by management of discovery, communication channels and data buffers. It is component-based, allowing developers to focus on writing minimal pieces of sensor-specific code, enabling an ecosystem of reusable sensor drivers. Integration of new sensors into applications is possible by downloading new sensor capabilities from an application market, without modifications to the operating system.

DeviceAnalyzer (Wagner et al. 2014) is a framework capturing the most comprehensive set of raw sensor data. While no additional processing is done, the application has been used to collect the largest, most detailed dataset of Android phone use publicly available to date.

Kraken.me (Schweizer et al. 2014) is a toolkit for users providing extensive sensing capabilities for mobile, online, and desktop context. By integrating hardware, software, and human sensors across device boundaries, Kraken.me provides comprehensive information to the user. The user can access that information through an online portal at http://www.kraken.me and other apps can make use of this data to provide context sensitive-services.

AWARE (Ferreira 2013) is an instrumentation toolkit for researchers of context-aware mobile computing, application developers and users. Using AWARE, raw data sensed from hardware, software and human sensors is converted to units of information (i.e., mobile context) that can be shared between other applications, sensors and humans alike. AWARE provides a foundation to create new mobile research tools for data mining and visualization. AWARE takes into account the wide range of interrelated sources of context information and the relationships amongst them, including the user's individual and social behaviour. AWARE is available at http://www.awareframework.com.

Table 1.1 summarizes the reviewed tools for mobile context-aware research. For each middleware the table highlights the potential audience (researchers, developers, users) and its sensing capabilities (hardware sensors, software sensors, humans). The table also distinguishes between two types of management: centralized (i.e.,

Table 1.1 Summary of mobile phone middleware for sensing data

	Audience			Sensing			Architecture		Context		
Middleware	R	D	U	HW	SW	U	Centralized	Distributed	Shared	Dynamic	Scalable
CORTEX	x			x	x		x		x		x
ContextStudio			x	x	x	x	x		x	x	
ContextPhone	x		x	x	x	x		x	x		
AWARENESS	x			x	x			x	x	x	
Momento	x			x	x	x		x		x	
MyExperience	x			x	x	x		x			
CenceMe			x	x	x			x		x	
EmotionSense	x			x	x		x			x	
Empath	x		x	x	x			x			x
Funf	x		x	x	x		x		x		x
Ginger.io	x		x	x	x	x		x	x		
SystemSens	x			x	x			x			x
Ohmage	x		x	x	x	x	x		x		
ODK Sensors		x		x				x	x	x	x
DeviceAnalyzer	x		x	x	x	x	x		x		x
Kraken.me			x	x	x	x	x		x		x
AWARE	x	x	x	x	x	x	x	x	x	x	x

R researcher, *D* developer, *U* user, *HW* hardware, *SW* software

on the phone itself) or decentralized (distributed among many devices). Finally, the table includes further *properties* of context such as *shared*, *dynamic* and *scalable* context (Dey et al. 2001). Shared context can be used locally on the mobile phone for other applications or devices; dynamic context can be extended in runtime and adapts the current context; and scalable middleware supports adding new sources of context beyond core contextual sources. S*hared* context is required for *multidisciplinary research* and *collaboration*, and provides *reusability*, *delegation*, and *accessibility* (e.g., *security*, *privacy*, *online visualization*) of context. *Dynamic* context supports mobile context *volatility*, such as *runtime adaptation* and *manipulation* (i.e., *reflection*, *frequency*). Lastly, *scalable* context provides support for context *heterogeneity*, *transparency*, *redundancy* and *portability*.

Making the transition from mobile phones to “smartphones”, in the true sense of the word, requires more tools that offer programming and development support. The development of “contextaware” applications remains challenging because researchers have to deal with obtaining raw sensor data, analyzing the data to produce context, and often writing code from scratch that require years of expertise to acquire. There is a lack of a *coherent* and *modular* repository of relevant tools. Research fragmentation is the *biggest* challenge for this field.

1.7 Summary

Obviously, researchers are fascinated by the prospect of *human sensors on the move*. We first discussed mobility and the versatility of smartphones as the two main properties responsible for this fascination. We then shortly discussed calibration and energy consumption as two examples of basic, open challenges every system that captures sensor data on the move faces. Lastly, we introduced 17 mobile context frameworks build to capture, process and analyse data.

The sheer number of systems available goes to highlight one of the core challenges for the future of human sensing. Trying to promote an open ecosystem of reusable tools to get new researchers and developers to build betters systems quickly and focus on understanding humans, i.e., their activity, goals and intentions, rather than solving technical challenges.

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Chapter 2
Sensing the Environment

Jan Theunis, Matthias Stevens, and Dick Botteldooren

2.1 Sensing the Environment: An Overview of the Field

2.1.1 New Approaches in Environmental Monitoring

Systematic environmental monitoring grew out of the concern that people's activities have distinctive impacts on the quality of the environment,[1] with sometimes detrimental effects on the health and wellbeing of all living organisms. This has led to the development of large scale monitoring networks to understand the sources, context and dispersion of various kinds of pollution. Such networks enable improved environmental policy, for instance by identifying appropriate pollution abatement measures and evaluating their effectiveness. The official monitoring networks are highly standardised using high quality precision instruments.

[1]The term *environment* is used here in the narrow sense of the biophysical environment in which organisms live, that affects their health and wellbeing, and that in its turn is affected by their activities. Sensing the environment then means assessing the state of the environment in which organisms live, in domains such as air, water, noise, radiation, ecology or biodiversity.

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Apart from official initiatives, a lot of ad hoc measurement campaigns are carried out by governmental authorities, scientists or non-governmental organizations to understand causes and effects of pollution on a more detailed scale, i.e. to get more spatially detailed information than official monitoring networks provide, to prepare local policy plans or pollution abatement strategies, or to investigate emerging non-regulated pollutants, such as ultrafine particles or endocrine disruptors.

Official monitoring networks typically focus on a limited number of sites at which measurements are carried out with a high level of accuracy (and accordingly a high cost per data). This approach is well suited for monitoring long-term trends in temporally averaged indicators, mainly if the pollutant concentration is only slightly influenced by local pollution sources. In such cases, the accuracy of the equipment allows to discover even the smallest trends. However, this monitoring approach is unable to capture spatial variability and short term fluctuations caused by local sources.

Current innovations in sensing technologies are leading to the development of miniaturised sensors that can be used as stand-alone devices, connected to smartphones or even embedded in smartphones. Provided that such sensors can be produced cheaply enough, they hold the promise of enabling new kinds of intelligent networks that allow monitoring of environmental parameters at significantly higher levels of spatio-temporal detail. Smartphones are attractive consumer devices in this respect because of embedded sensors such as microphones, GPS receivers, optical sensors or accelerometers and their processing and transmission capabilities. Their wide array of local connectivity options (e.g. Wi-Fi, Bluetooth, NFC, USB) makes connecting them to additional external sensors relatively easy. Their touch screens allow developers to design intuitive interfaces for annotation of sensed data, for example to enrich purely quantitative measurement data with qualitative information (e.g. contextual parameters and subjective opinions) to facilitate interpretation. Portability and robustness of these new sensing platforms allow for mobile data collection during walks, bicycle or car rides which could allow for widespread coverage as compared to the stationary monitoring stations. In comparison with conventional, high-accuracy and high-cost environmental monitoring networks, these new sensing networks have the potential to generate environmental data that are more detailed and potentially enriched with contextual information, and to do so at a reasonable price.

These technical developments create opportunities for participatory data collection and monitoring (Burke et al. 2006; SCU–UWE 2013; Stevens 2012). There is a long tradition, especially in the UK, of *citizen science* and participatory data collection in the domains of nature conservation, biodiversity and wildlife research. Citizen scientists have surveyed for and monitored a broad range of taxa, and contributed data on weather and habitats. Roy et al. (2012) give an overview of available technology. Several apps are available that allow to collect geo-tagged photos of spotted flora and fauna, and annotate them. Typically these apps are connected to web-based data sharing platforms where users can upload and visualise data. Examples include iSpot (http://www.ispotnature.org/), iNaturalist (http://www.inaturalist.org/) and eBird (http://ebird.org/). Most of these smartphone apps only make use of geo-tagged and annotated photographs. However, there are some examples which do rely on embedded or add-on sensors. The New Forest Cicada app (http://newforestcicada.info/app) detects the high-frequency call of a cicada species through spectral analysis of audio captured through the phone's microphone (Zilli et al. 2010). The Indicator Bats Program (http://www.ibats.org.uk) uses an ultrasonic detector to capture bat echolocation calls along car transects (Roche et al. 2011).

Initiatives to make radiation detectors available to the public at large received a boost of public interest after the nuclear incident in 2011 at Fukushima, Japan. Ishigaki et al. (2012) describe an ultra-low-cost radiation monitoring system using a PIN photodiode detector (POKEGA) connected to a smartphone via a microphone cable. The smartphone software application handles the complex processing required. Wikisensor (http://wikisensor.com/) and iRad (http://www.iradgeiger.com/) are applications for the iPhone. They are based on the fact that the camera lenses, including CMOS sensors, found on most smartphones, are sensitive to gamma and X waves emitted by radioactive sources.

A lot of attention also goes to noise and air quality sensing, e.g. in urban environments. They are discussed in detail in the following sections.

Obviously, there is more to environmental monitoring than collecting data. Data collection, data processing, presentation and visualisation, and finally interpreting the results and drawing conclusions is often an iterative process in which the collected data are combined with the skills and know-how of researchers to come to valid conclusions. In many cases novel sensors and the collected data do not have the same high quality standards as the analytical equipment used in classical monitoring activities. Data validation and quality control are thus critical issues. Mobile monitoring data are also fundamentally different from stationary monitoring data and require adapted monitoring strategies and data processing methods. Chapter 11 of Part 2 of this book will discuss how these aspects can be embedded in participatory monitoring campaigns.

2.1.2 Requirements for Sensing Devices

In this text we will distinguish between monitors, sensing devices and sensors (Box 2.1). Monitors are high-end instruments for continuous measurements. Sensing devices rely on low-cost sensors to give continuous quantitative readings of a physical property.

There is a strong and intrinsic link between the technological features of sensing devices and the way they can be used in monitoring campaigns. Whether a sensing device is fit for monitoring or not depends on the qualities of the sensing device, on the features that are monitored and on the goals of the monitoring campaign.

Features that are monitored have a temporal and a spatial component. Both can be rather constant or highly variable. Some features, such as air quality or noise, can be highly variable both in space and time.

Spatial and temporal resolution of the measurements has to be in line with the spatio-temporal variability of the features that are monitored. The measurement resolution, the number of point measurements per unit of time or per unit of space, depends both on the temporal resolution of the individual sensor and on the way individual sensors are deployed. Next to the temporal resolution the sensing device is also characterised by its response time. A microphone will respond almost immediately to changes in the sound level. Chemical sensors may respond quite slowly to changes in the air, e.g. because of slow chemical reactions or diffusion processes at the sensor surface.

For *continuous stationary measurements* temporal resolution is constrained by the temporal resolution of the sensor. Sensors with a high response time will lag behind and will not be able to capture short-term changes. The spatial resolution is determined by the density of the measurement grid, i.e. the distance between the individual sensors.

For *continuous mobile measurements* the spatial resolution is determined by the track that is covered, but also by the temporal resolution of the measurements and the speed as the mobile sensor will have travelled a certain distance between two consecutive measurements. A slow response time will lead to a shift in space of the measurements and to an underestimation of the small scale spatial variability. Temporal resolution is determined by the number of repeated measurements, i.e. the number of times the sensing device passes by a certain location.

For *discontinuous monitoring devices* temporal and spatial resolution depend fully on the actions of the operator.

Other important features that determine the way a sensing device can be used are its size and weight, (in)dependence from power supply, data logging and data transfer capabilities, data processing capacities and complexity, i.e. required skill to operate it. The features of a sensor will thus determine the way it can be used.

Box 2.1: Sensors and Monitors

The Oxford English Dictionary defines a sensor as "a device which detects or measures a physical property and records, indicates, or otherwise responds to it". A monitor is defined as "a device used for observing, checking, or keeping a continuous record of something". Whereas the term monitor clearly refers to a final consumer product, the word sensor is used both in the meaning of the basic sensing element as in the meaning of the final consumer product.

For the sake of clarity we will use a terminology that takes into account different stages in the level of integration of the sensing elements in final devices:

- A *basic sensor* or just *sensor* is the actual sensing element that transforms an external physical property into an electrical response, together with its packaging and pins to plug it in on an electronic circuit board.

(continued)

Box 2.1 (continued)

- A *sensor device* or *sensing device* is a final consumer product that contains sensors (and often peripheral equipment to make the sensors work in the required circumstances), and gives a quantitative reading of the observed physical property to the user. The term sensor device will be used when we make explicit reference to devices containing basic sensors that can be mass-produced at a relatively low cost (i.e. roughly between a few 100 euros and a few 1000 euros).
- A *monitor* is a final consumer product for high-quality continuous measurements at a high cost (several 1000 s euros)

2.2 Monitoring Ambient Air Quality

2.2.1 Monitoring Requirements

Ambient air pollution is estimated to cause 3.7 million deaths each year (WHO 2014). The air we breathe contains a complex mixture of gases and particles that is highly variable in space and time. Components such as NO_2, SO_2, O_3, CO, particles (PM_{10}, $PM_{2.5}$, ultrafine particles, black carbon or soot), heavy metals and volatile organic compounds (VOCs) have all been associated with detrimental effects on human health and/or ecosystems (WHO Europe 2013). Diseases caused by air pollution include respiratory infections, heart diseases, and lung cancer.

The outdoor air quality is affected by emissions from different sources, such as traffic, industry, agriculture and buildings (i.e. heating). Emitted gases and particles are dispersed by wind and atmospheric turbulence, and can travel over long distances. Pollutants can be transformed in the atmosphere through physical or chemical reactions, and new pollutants can be formed. For some pollutants significant small scale spatial differences in concentration can occur, whereas others are relatively uniform over larger areas. Effects on people's health or on ecosystems are specific for each pollutant. As a result several pollutants have to be monitored over representative time and spatial scales to give a comprehensive overview of the air quality.

In most industrial countries most of the above-mentioned pollutants are regulated, and are monitored in official monitoring stations. These monitoring networks have been part of a successful approach to significantly cut emissions of several air pollutants and improve air quality in recent decades (EEA 2013, U.S. EPA 2012). The monitors that are used, are mostly expensive (typically more than 10,000 € per component). They give well controlled and comparable measurements, but due to their high cost spatial coverage is rather low. Additional monitoring is thus most relevant for components that show strong local variability, and that are most harmful to people's or ecosystems' health. In that sense recent literature clearly shows that intra-urban variability is much higher for ultrafine particles (UFP) and black carbon (BC), than for PM_{10} or $PM_{2.5}$ (e.g. Peters et al. 2013). Although UFP and BC are not regulated, there is increasing evidence of their association with health effects (Janssen et al. 2013; WHO Europe 2013). NO_2 and O_3 are also strongly related to health effects, although health effects associated with NO_2 may be caused partially by other combustion-related pollutants that are emitted together with NO_2 (WHO Europe 2013). Spatial variability is less apparent for O_3. SO_2 and CO are also regulated but in practice levels in ambient air are seldom a cause for concern in most industrialised countries. In industrial areas VOCs can be relevant.

Requirements for indoor air quality monitoring are quite different from outdoor. Outdoor pollutants infiltrate in a building depending on its isolation and ventilation rate. But indoor air quality is also affected by typical indoor sources (i.e. combustion processes, building materials, maintenance products). Typical indoor VOCs, some of which with known health effects, are different from those encountered outdoors (e.g. formaldehyde). Typical concentration levels for VOCs are also in the ppb range. CO can be a direct health threat but only at concentrations way above those usually measured in ambient air. Elevated concentrations of CO_2 (>1000 ppm) can lead to dizziness and reduced ability to concentrate. Elevated CO_2 concentrations can also be used as general indicator for poor ventilation.

For most pollutants the challenge is to quantify $\mu g/m^3$ or parts-per-billion (ppb) levels in a complex mixture of gases and particles with varying temperature and humidity.

2.2.2 Monitoring Gas Concentrations

Instruments for personal or stationary monitoring of CO and O_3 based on low-cost electrochemical and metal-oxide gas sensors are commercially available already for quite some time. Milton and Steed (2007) started using mobile GPS tracked ICOM sensor devices to map CO already in 2005. In an effort to initiate large scale volunteered monitoring programs, several projects, research groups or companies developed portable devices, integrating low-cost gas sensors, GPS and mobile phones (e.g. Dutta et al. 2009; Zappi et al. 2012; Mead et al. 2013). However, some of them focused on the electronics and systems integration, power issues, wireless data transfer, data storage and visualization and paid less attention to the performance and limitations of the used gas or particle sensors.

As a general rule the current generation of commercially available basic metal oxide or electrochemical gas sensors cannot be readily used for ambient air quality monitoring. When using these sensors for outdoor air quality measurements, the main issues are the inherent lack of sensitivity, sensitivity to changes in temperature and humidity, lack of selectivity towards other gases, stability and baseline drift. An important part of the complexity, and associated high cost, of air quality monitors is exactly related to the fact that they have to be highly sensitive, component-specific and independent from external environmental conditions (i.e. weather effects).

2.2.2.1 Low-Cost Gas Sensors

Low-cost basic sensors are commercially available for a broad range of gas species including NO_2, NO, CO and O_3. Prices range from a few to 30 € for metal oxide sensors, and from 50 to 80 € for electrochemical sensors. However, most of these have not been designed to measure ambient air quality. Typical concentration levels for pollutants in ambient air will be much lower than those most commonly experienced in industrial safety monitoring or in emissions testing for which most low-cost gas sensors have traditionally been applied. Sensor specifications and calibration curves provided by the suppliers relate to their typical operating range which is in most cases a factor 100 to 1000 higher than concentrations encountered in ambient environments. Reported sensitivities and detection limits often relate to controlled laboratory conditions for exposure to single gas species.

Parts-per-billion (ppb) level sensitivities have been demonstrated in laboratory conditions for several gas sensors (e.g. Brunet et al. 2008; Afzal et al. 2012; Mead et al. 2013). However, when used in ambient environment intrinsic low detection limits are overshadowed by temperature and humidity effects, and by cross-interference (Afzal et al. 2012; Mead et al. 2013). Response times to gas concentrations in the ppb range can also be significantly longer than those specified for gas concentrations in the ppm range. Finally, repeatability and long term sensor baseline drift are other important issues.

Table 2.1 shows the result of a comparison of sensor measurements with reference monitors from the official Flemish air quality monitoring network between October 2012 and April 2013. For this comparison commercially available gas sensors were collocated right next to the reference monitors' air inlet at a monitoring station at a traffic location. The 30 min averaged sensor data were compared with reference data for CO, NO, NO_2 and O_3. The ozone sensors showed a good correlation (0.83) with the reference ozone measurements. Some CO sensors (Alphasense CO-BF and e2v MiCS-5525 CO) showed moderate (>0.50) correlation with the reference CO measurements. The correlations for the NO_2, NO_x and some

Table 2.1 Cross-correlation between 30-min averaged sensor measurements and reference gas measurements from station 42R801 of the official Flemish air quality monitoring network

	Pollutants			
Sensors	CO	NO	NO_2	O_3
Alphasense CO-BF	0.52 (0.16)	0.41 (0.11)	0.34 (0.11)	−0.32 (0.14)
e2v MiCS-5521 CO	0.31 (0.04)	0.32 (0.04)	0.34 (0.04)	−0.09 (0.11)
e2v MiCS-5525 CO	0.60 (0.02)	0.51 (0.05)	0.56 (0.05)	−0.71 (0.05)
Figaro TGS 2201 CO	0.25 (0.02)	0.32 (0.01)	0.17 (0.00)	−0.48 (0.01)
Figaro TGS 2201 NO_x	−0.78 (0.01)	−0.40 (0.06)	−0.24 (0.05)	0.47 (0.05)
e2v MiCS-2710 NO_2	−0.58 (0.02)	−0.40 (0.06)	−0.31 (0.08)	0.64 (0.07)
e2v MiCS-2610 O_3	−0.67 (0.06)	−0.56 (0.02)	−0.55 (0.05)	0.83 (0.07)
Applied Sensors AS-MLV VOC	0.63 (0.02)	0.43 (0.17)	0.53 (0.15)	−0.44 (0.26)

Averages of four sensors are shown together with the standard deviations between brackets

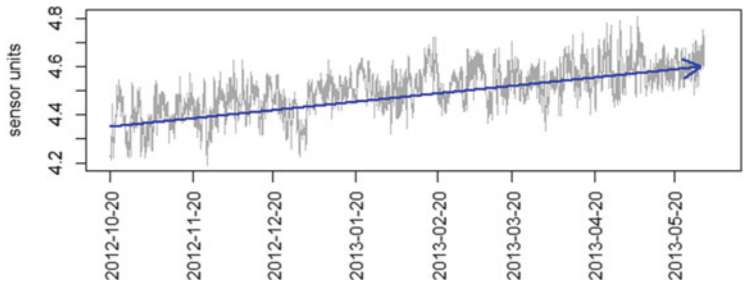

Fig. 2.1 Drift in sensor output signal occurring through time for a metaloxide VOC sensor

of the CO sensors was low. The deviations between sensors of the same type were generally low, indicating similar responses of the different sensors to changing outdoor concentration levels. Cross-sensitivities are observed when sensor data are compared with reference measurements of different pollutants. Some of the observed cross-correlations cannot be explained by known correlation between the ambient concentrations of the pollutants.

Long term sensor drift, i.e. continuous long term changes in the sensor output, was observed for several sensors (Fig. 2.1). These effects are related to sensor ageing, i.e. irreversible changes at the sensing layer.

Recently, Alphasense has a series of electrochemical sensors on offer that specifically target ambient air monitoring (e.g. O_3, NO_2, NO and CO) (Alphasense 2015). Appropriate low noise electronics have to be used to attain the full sensor response. Good design of the sensor, housing and electronics and intelligent data analysis are required, i.e. when measuring O_3 and NO_2. Specifications have to be verified in real ambient conditions.

In the last years a lot of research has been done on the use of nanomaterials and nano-electronics to reach better gas sensing performances and lower power consumption. Nanostructured materials are promising for achieving high sensitivity, but lack of selectivity and stability remain major issues. Most results are acquired in laboratory conditions, and have not yet made their way to field applications. Overviews of the state of the art and future developments are given in Llobet (2013), Afzal et al. (2012) and Basu and Bhattacharyya (2012).

2.2.2.2 Gas Sensing Devices

Different strategies are implemented to improve the sensitivity or selectivity of gas sensors or to compensate for drift. They are based on modulation of temperature regimes, modulation of the flow over the sensor, removal of interfering gases through scrubbers and filters, or compensation for temperature and humidity (Brunet et al. 2008; Bur et al. 2014; Mead et al. 2013). This results in a higher complexity and significantly higher cost of the final device. Prices for commercial devices range from several hundred to several thousand euro for single gas species. The Aeroqual devices are a well described example of how a combination of different techniques leads to the development of an actual device for outdoor air quality monitoring (Williams et al. 2009). Recently also several other devices are commercially available, but only few reports exist in which the use of these devices is compared to measurements from reference devices.

Gerboles and Buzica (2009) evaluated four commercially available ozone measurement devices. Sensitivity to humidity in particular, but also to temperature and in some cases wind speed were apparent during laboratory tests. They compared outdoor measurements with the devices to measurements from a co-located reference monitor. Reasonable measurement results were possible after a field calibration using O_3 reference measurements. Probably the calibration is to a certain extent specific for a site or for different periods over the year. Hasenfratz et al. (2012) made a portable measurement system based on the commercially available OZ-47 O_3 sensor module. They estimated measurement accuracy by comparing mobile sensor readings that were measured in the spatial and temporal vicinity (<400 m and < 10 min) of reference monitoring stations. The errors are on average 2.74 and 4.19 ppb compared to high-quality measurement instruments which they consider sufficient to create accurate air pollution maps considering that the daily ozone concentration typically ranges between 0 and 70 ppb.

However, as mentioned before large scale measurements for O_3 have a limited added value. Measurements of NO and NO_2 would be more interesting, but are even more challenging. Next to baseline drift, cross-sensitivity towards ozone is a major issue for both metal oxide sensors and electrochemical NO_2 sensors (Afzal et al. 2012; Mead et al. 2013). Delgado-Saborit (2012) compared an Aeroqual handheld NO_2 monitor to a reference monitor at 1 h temporal resolution. The concentrations measured by both methods follow a similar trend but correlation is only moderate ($R^2 = 0.63$).

Mead et al. (2013) demonstrated that, when correctly configured, the intrinsic detection limit, sensitivity, noise characteristics and response time of electrochemical sensors are compatible with their use in ambient air quality studies. They used variants of commercially available electrochemical NO, NO_2 and CO sensors (Alphasense, UK) that were optimised for use at ppb level through improved techniques for electrode and sensor manufacture as well as careful design of a low-noise conditioning circuitry. They further present data post-processing procedures to correct for baseline sensitivity to temperature and humidity and to correct for O_3 interference. They compared the corrected sensor data with hourly averages of co-located reference monitors over a 5 day period, and found promising agreement. This is a clear example of an integrated approach in which issues are addressed at the level of the sensor itself, at the level of the sensor electronics and through data post-processing.

Piedrahita et al. (2014) developed parametric regression-based calibration models for commercially available metaloxide sensors, based on both laboratory and field experiments. They included temperature, humidity and a time factor to account for drift. Their experiments revealed that field calibrations using standard reference monitors provide more accurate concentration estimates than laboratory calibrations. However, they didn't test their calibration models on independent data.

2.2.2.3 Sensor Arrays and Multivariate Field Calibration

A way to overcome the gas sensor limitations is the utilization of multivariate information based on information from a set of different gas sensors and/or temperature and humidity sensors together with pattern recognition techniques. This is also known as an electronic nose (e-nose). The sensor array is composed of a selected group of non-specific gas sensors. The different response rates and intensity levels of the sensors in the array will produce characteristic response patterns (i.e. a "finger print") when exposed to volatiles with specific chemical content.

Only few works report the use of e-noses for ambient air quality measurements. De Vito et al. (2009) deployed a low cost multi-sensor device based on seven solid-state sensors at a roadside location 13 months. Models to estimate benzene, CO and NO_2 levels was performed by means of a statistical sensor fusion algorithm, using a neural network (NN) and data from a governmental station as reference. Two weeks of training for their NN was enough to have acceptable results for CO and NO_2 estimation for 6 months. NO_2 levels were quite high with daytime concentrations roughly between 80 and 160 $\mu g/m^3$.

Another example of this approach is the EveryAware SensorBox. A gas sensor array is used to estimate black carbon concentrations in ambient air. Outdoor calibration was carried out for scaling and calibration. A neural network model was parameterized using the calibration data. The model is then used to estimate the black carbon concentration from sensor array measurements. This example is discussed in more depth in Chap. 7 of Part 1.

Sensor arrays seem to have a high potential to counteract selectivity and calibration issues. On the other hand, the sensor array requires a reference device to be deployed for a certain period in its proximity to develop the calibration model. The calibration model can be site and time specific as the specific gas composition will be different for different sites and different seasons. Performance downgrades with time as the gas sensors deteriorate.

2.2.2.4 Mobile Monitoring with Low-Cost Sensors

Most results that were discussed in the previous paragraphs, relate to stationary measurement set-ups. Mobile measurements lead to additional difficulties. As mentioned before field calibration can be site specific, which limits the use of the sensing device to similar locations. The sensor response might be quite different in a busy traffic location and in an urban green. The response time of the sensors is another important constraint. Many gas sensors exhibit response times of several minutes which leads to a spatio-temporal shift in the measurements. In practice a response time of 1 min corresponds to a distance travelled of 80 m for a pedestrian and more than 200 m for a cyclist. In general metaloxide gas sensors have higher response times than electrochemical sensors which makes them less suitable for mobile use.

2.2.3 Monitoring Particle Concentrations

Particulate matter (PM) in ambient air is a heterogeneous mixture of individual particles of different origin, size, shape and composition. Aerodynamic PM diameters are in the 0.01–100 μm range (Fig. 2.2). Coarse particles and PM in the accumulation mode contribute the most to the PM mass in the air. Ultrafine particles (<0.1 μm aerodynamic diameter) have very small mass but are found in very high numbers in air. Primary particles are directly emitted, whereas secondary particles are formed in the atmosphere from precursor compounds. The coarser particle fraction (e.g. with an aerodynamic diameter between 2 and 100 μm) is mainly composed of geological material, pollen and sea salt. Particles smaller than 2 μm include heavy metals, nitrates and sulphates, and carbon particles.

The standard metrics that are actually used in regulation are based on the mass concentration (in μg/m^3) of all particles with an aerodynamic diameter lower than 10 μm (PM_{10}) or 2.5 μm ($PM_{2.5}$). More recently particle number count (PNC, in number per cm^3) is used to quantify the smallest particles (ultrafine particles or UFP) as they hardly contribute to the total mass, but might have important health effects. Elemental carbon (EC) or Black carbon (BC, soot) measurements relate to carbon particles from incomplete combustion emitted as tiny spherules ranging in size between 0.001 and 0.005 μm, and aggregating to particles of 0.1–1 μm.

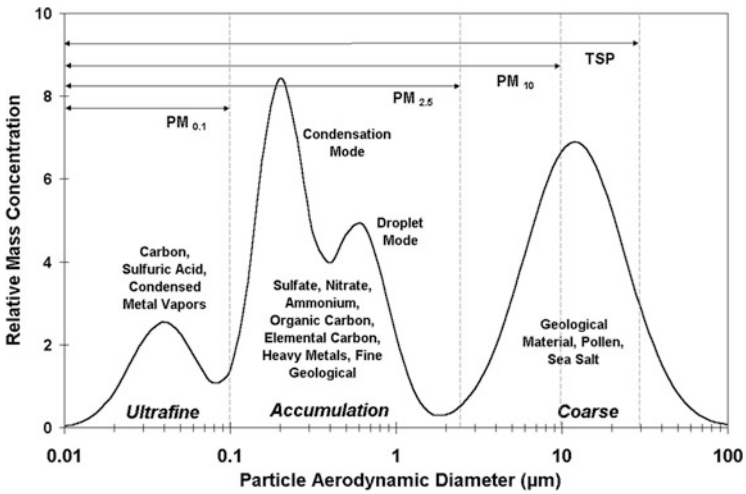

Fig. 2.2 Relative mass concentration in function of the particle aerodynamic diameter

A variety of particle monitors, sensing devices and sensors is available on the market to determine the particle mass concentration in air samples. Different physical principles are used. The most straightforward is the gravimetrical method where particles are actively collected on a filter medium sucking a known volume of air through the filter. Pre- and post-particle collection filter weighing is used to determine the particle mass, and particle mass is divided by the volume of the air sample to determine the average particle mass concentration during the sampling period. Size-selective heads can be used to sample a predefined fraction of particles (e.g. PM_{10} or $PM_{2.5}$). Other particle monitors use Beta attenuation, UV and infrared attenuation, light scattering or oscillating microbalance technology to measure particle concentrations.

Below, we focus on portable particle monitors and particle sensing devices that could potentially be used in ubiquitous or participatory air quality sensing. Participatory monitoring initiatives so far rarely focused on particulate matter. Most existing particle monitors are still quite big, heavy and costly to be used in large scale applications. Further development and miniaturization of particle sensing devices is likely to increase their applicability for participatory sensing.

2.2.3.1 Portable Particle Monitors

Portable hand-held instruments are available for measuring fine and ultrafine particles and black carbon. Examples are the TSI DustTrak, which measures the mass concentration of particles between 1 and 10 μm; the TSI P-trak, which measures the number concentration of particles smaller than 1 μm. The micro-Aeth AE51 measures black carbon mass concentrations. Although these devices are performing relatively well, they have to be compared on a regular basis with standard monitoring devices and sometimes correction factors have to be applied (Dons et al. 2012; Wallace et al. 2011). More recently new devices to measure ultrafine particles have become commercially available (e.g. Mills et al. 2013). With some training, these devices can be used by non-specialist users (Buonocore et al. 2009; Dons et al. 2011). Although primarily intended to monitor personal exposure to particles, they can also be used for general monitoring purposes. But, they are expensive (roughly between 5000 and 10,000 €) which limits their widespread use. In Chap. 10 of Part 2 we will explain in more detail how this kind of devices can be used in participatory monitoring studies.

2.2.3.2 Portable Particle Sensing Devices

Shinyei Technology produces light-weight optical particle counters for different size classes costing about 15 €. The system can report the number of particles or the particle concentration with respect to the selected particle size limits. The AES-1 monitors particulates of 0.5 μm or larger. The AES-4 has particle sizing into four groups: 0.3 and larger, 0.5 and larger, 1.0 and larger, 2.5 (or 5.0 μm) and larger. The PPD42NS measures concentrations of particles larger than 1 μm. Other particle sensors from Shinyei include PPD20V and PPD60V. The Sharp GP2Y1010AU0F is also a compact optical dust sensor of similar cost. It uses a conversion function to convert particle counts to dust mass concentration. The Alphasense OPC-N1 optical particle counter is another small and light weight optical device for measuring particle concentrations of sizes between 0.5 and 15 μm aerodynamic diameter. The Alphasense OPC-N1 optical particle counter is another small and light weight optical device for measuring particle concentrations of sizes between 0.5 and 15 μm aerodynamic diameter. Dylos corporation manufactures compact air quality monitors such as the DC 1100 Air Quality Monitor. The DC 1100 Air Quality Monitor is a laser particle counter to count individual particles of small (>0.5 μm) and larger (>2.5 μm) sizes. The latter two devices are more expensive (200–300 €) but still far below the prices of high range monitors.

Several of these devices have been tested for use in monitoring case studies. Choi et al. (2009) used a Shinyei PPD42NS sensor in combination with several low cost gas sensors as sensor nodes in their APOLLO system. Holstius et al. (2014) made a comparison of the Shinyei PPD42NS sensor with commercially available optical instruments (GRIMM Model 1.108, DustTrak II model 8530) and a reference particle monitor (BAM-1020, MetOne Instruments) at a regulatory monitoring site in Oakland, California. The authors observed negligible associations with ambient humidity and temperature and linear corrections were sufficient to explain 60 % of the variance in 1 h reference $PM_{2.5}$ data and 72 % of the variance in 24 h data. Performance at 1 h integration times was comparable to commercially available optical instruments costing considerably more. Comparison between the hourly $PM_{2.5}$ measurements between Shinyei PPD42NS sensor and Grimm spectrometers Model 1.108 showed *r*-square values of higher than 0.90. The $PM_{2.5}$ mass concentration (24 h average) during the experiments ranged between 2 and 21 μg/m^3. Relative humidity (between 10 and 60 %) and temperature (20–30 °C) were within the operating conditions provided by the manufacturer.

Budde et al. (2013) used Sharp GP2Y1010 sensors in their study on enabling low-cost particulate matter measurement for participatory sensing scenarios. They ran different laboratory and outdoor tests and applied state-of-the-art data models for noise reduction and sensor calibration. When the calibration model was used for consecutive measurement runs, the baseline jumped and the sensors showed drift over time. Baseline drift could be modelled as a function of time. A temperature correction model was introduced in the sensor calibration. On-the-fly calibration with reference measurements is introduced for baseline rescaling of the sensors.

Recently, Steinle et al. (2015) published personal exposure monitoring data of $PM_{2.5}$ in indoor and outdoor microenvironments using the Dylos 1700 device. A validation period of nearly 120 h was used to develop linear functions to convert the particle number counts to mass concentration using simultaneous measurements with a TEOM-FDMS monitor. Afterwards, the Dylos was used for stationary and mobile measurements at different micro-environments. Additional data sources were used for the interpretation. However, the authors correctly state that low-cost air pollution sensing devices do not (yet) obtain the same precision as reference or equivalent methods for measuring PM.

Most case studies using low-cost particle sensing devices are still in an experimental phase in a confined spatial and temporal setting, i.e. under relatively controlled circumstances where a calibration function is developed based on simultaneous measurements with reference instrumentation at the site of final deployment. Long term validity of these calibration functions and their transferability to other areas is largely unknown at this stage.

Next to these experiments with commercially available low-cost particle sensors attempts are also ongoing to further miniaturise particle sensors.

Paprotny et al. (2013) present a micro electro mechanical systems (MEMS) particulate matter (PM) sensor. The sensor measures only $25 \times 21 \times 2$ mm in size. An air-microfluidic circuit separates the particles by size and then transports and deposits the selected particles using thermophoretic precipitation onto the surface of a microfabricated mass-sensitive film bulk acoustic resonator (FBAR). Lab experiments with diesel exhaust and tobacco smoke indicate that it could reach a detection limit below 10 $\mu g/m^3$. The sensitivity can be further increased by increasing the flow through the microfluidic channel. Calibration of the FBAR module is currently FBAR specific. The effects of external environmental factors such as temperature and humidity on the sensitivity of the sensor should also be investigated. The authors envision future devices to contain microfabricated temperature and relative humidity sensors in order to compensate for these effects.

A novel particle sensing system employing zinc oxide based Solidly Mounted Resonator (SMR) devices for the detection of airborne fine particles (i.e. $PM_{2.5}$ and PM_{10}) is currently under development (Thomas et al. 2016). Particles are detected by the frequency shift caused by the mass of particles present on one resonator with the other acting as a reference channel that should compensate frequency shifts that are not related to changes in particle concentration.

2.2.4 Conclusion

Ambient air pollution causes an important health risk, for example in urban environments with a lot of traffic. There is a clear need for additional detailed air quality monitoring for those components that show strong local variability, and that are relevant for people's or ecosystems' health. However, at this point in time there are no readily available solutions for ubiquitous air quality sensing. No low-cost mass produced sensors exist that can directly measure crucial parameters such as PM, BC, NO_2 or O_3 in ambient environments. Their possible availability will be a matter of several years. Some encouraging examples show that the use of low-cost sensors has potential but requires know-how on sensing principles, careful electronics design, laboratory and field testing, and complex data post-processing or field calibration procedures, requiring serious interdisciplinary development efforts. Portable particle monitors and particle sensor devices are available but they are relatively expensive and large which hampers their widespread use. Still there is a clear potential for participatory air quality sensing if monitoring targets are well defined. Possible monitoring schemes will be discussed and illustrated with examples in Part 2.

2.3 Sound Monitoring

2.3.1 Environmental Sound and Its Impact

Noise is a term that people use to refer to unwanted sounds. *Environmental noise* is the term commonly used to refer to noise people are exposed to in their daily lives as a result of various human activities, such as those related to transport, industry and leisure. The labelling of particular sounds as noise is strongly influenced by personal, contextual and cultural factors. Whether the sound is observed at home or in a public space is one of the strongest and most obvious contextual factors.

Since a couple of decades the more general role of *sound* in the public space has become the focus of attention of scientists and practitioners. In this new paradigm, sound is regarded as a resource, and the *soundscape* as an element to be carefully designed and crafted as an integral part of urban design which contributes to the overall well-being of the citizen. This also leads to a strong focus on meaning and appraisal of the sound within its context. Matching monitoring techniques capable of sound identification are needed.

The detrimental effects on health and quality of life induced by long-term exposure to high levels of environmental noise are now widely recognised. The WHO estimates that across the population of western Europe a up to 1.6 million healthy years of life are lost every year due to exposure to environmental noise (WHO Europe 2011). In 2011 the estimated overall societal cost of traffic noise in the EU amounted to € 40 billion a year (European Commission 2011). Annoyance caused by noise can cause chronic stress, anxiety, hypertension and increased risks of cardiovascular diseases. Other adverse health effects include cognitive impairment in children, sleep disturbance, and even tinnitus and hearing loss (WHO Europe 2011). Reported noise annoyance is often used to characterise and estimate the associated health risks. However, even when not consciously perceived, instantaneous reactions of the autonomous nervous system to sound exposure can also contribute to the above-mention hypertension (Lercher 2007). *Noise events*, short-lasting but highly noticeable changes in the environmental sound (e.g. the sound of a train, ambulance or low-flying plane), are known to play an important role in reducing sleep quality.

From a health perspective, the importance of restorative environments has to be acknowledged as well. Green, natural environments and human voices are known to enhance mental restoration (Kaplan and Kaplan 1989; Lam et al. 2010).

2.3.2 Monitoring Requirements

Under the influence of legislation such as the *European Noise Directive* (European Parliament and Council 2002), source-specific *strategic noise maps* have become the conventional method for large-scale assessment of environmental noise. These maps are based on calculations rather than sound level measurements. This method allows to capture the overall spatial distribution of noise, particularly caused by road, rail and air traffic, relatively well. However, when the goal is to capture the smaller spatio-temporal variations in traffic noise, as well as sound resulting from industrial and recreational activities, specific noise events, or sound affecting vulnerable areas (such as schools), it is beneficial, or even required to complement conventional noise maps with more specific and localised monitoring data (Stevens 2012).

In comparison to most other pollutants that can be sensed, sound carries a huge amount of information which can be exploited to identify the nature and the source of the sound.

The primary acoustic parameter which is typically measured is *sound pressure level*, or *sound level* for short, which is a relative measure of the amplitude of sound waves,[2] denoted as L_p expressed in decibels (dB). Sound level is related to *loudness*, which is the subjective measure of how loud particular sounds appear to humans. However, human hearing is not equally sensitive (or responsive) to all frequencies. Therefore, sound level measurements are typically frequency-weighted resulting in an *A-weighted sound* (*pressure*) *level*, expressed in dB(A). To assess environmental noise sound level is typically averaged over set intervals, resulting in the *equivalent continuous sound level*, denoted as L_{eq}, often referred to as *overall* sound level. Equivalent A-weighted levels averaged over 1 h have become very popular basic indicators for the assessment of potential noise exposure effects such as annoyance, hearing damage risk, cardiovascular disease risk and sleep disturbance (WHO Europe 2011). However, most studies proving their predictive power implicitly or explicitly assume that a certain noise source dominates the sound environment, e.g. road traffic sound.

Measuring the *loudness level* (ISO 532:1975)[3] of a complex sound[4] allows to obtain a better estimate of the effects of the environmental sound on humans. It accounts for tonality and clearly noticeable sound peaks, and for the impact of low frequencies. It is therefore worthwhile to include those in more advanced measurements. The meaning of the sounds present in a sound environment is equally important to assess their impact on human health. Measurement systems mimicking

[2]Changes in ambient pressure of a medium (typically air), propagating away for the source of the sound.

[3]Loudness level, denoted as L_N, is a more accurate way to quantify the perceived loudness of sounds, taking into account not only amplitude and frequency but also masking and duration of exposure.

[4]*Complex sounds* are sounds composed of multiple frequencies, as opposed to single-frequency *pure tones*. Virtually all sounds we hear in our daily lives are complex.

human auditory stream segregation are being designed (Boes et al. 2013). Based on a detailed measurement of the sound, these systems try to predict what sounds a human observer is likely to hear (Oldoni et al. 2013).

Measurement strategy and equipment will be different for monitoring the sound in a city to feel its "pulse" or to prepare for more active soundscape design, than for evaluating compliance with noise regulations. For the latter, standardisation of measurement equipment in the form of type classification and strict requirements on measurement location and conditions are included in the national, regional, or supranational regulations. For the former, requirements on measurements strategy and equipment can be more relaxed.

To take into account the local character of noise one can opt for fixed measurement stations that are carefully located to cover all typical situations in the area, e.g. all road types, or one can prefer mobile measurements. The latter allow to quickly obtain a spatial distribution, yet diurnal variations are difficult to grasp. Mobile noise measurements need to be performed with care. In quite environments the noise produced by the observer walking or cycling can disturb the measurements. Sound recognition—or even spectral analysis—can be very helpful to eliminate footsteps or bicycle noise. Citizens could also be asked to move freely and select the sounds and sound levels that they think are relevant. The map constructed in such a way may be less statistically relevant but it could still give useful information for identifying noise problems.

2.3.3 Sound Monitoring Devices

2.3.3.1 Microphone Requirements

The microphone is the most important part of a sound monitoring device. A measurement microphone should have a linear, distortion free response as a function of sound amplitude, a flat spectral response, a low noise floor, limited disturbance of the sound field and limited sensitivity to temperature changes, vibration or electromagnetic radiation. The IEC standards (i.e. IEC 61672-1:2013, 61672-2:2013, 61672-3:2013) specify different categories of sound level meters, based on the accuracy and precision requirements they must meet. The highest-quality category is *class 1* and is aimed strictly at professional usage. Class 1 equipment uses classical measurement microphones of the electret condenser type, which have a low noise floor (20 dB(A) or less) and a flat frequency response over most of the auditory frequency range (20 Hz–20 kHz). They are mounted on a sound level meter that is shaped to avoid reflections at high frequencies. For long term monitoring weather protection is added and the microphone is typically mounted in a free standing position (e.g. on a tripod). Often the monitoring station includes a self-calibration such as charge injection. These high-end monitoring stations are typically too expensive (several thousands of euro) to be used for constructing dense measurement networks or for participatory sensing. Lower quality *class 2* devices are significantly cheaper, but depending on their feature set can still cost several hundreds of euros. When a microphone is used outdoors, wind may significantly disturb the measurement as the turbulence caused by the wind blowing around the microphone produces low frequency signals that are registered as sound. For long-term or permanent monitoring stations protection for wind, rain and condensation is crucial.

2.3.3.2 Cheap Microphones for Use in Sensor Networks and Mobile Monitoring Stations

The quality of microphones designed for consumer electronics is constantly increasing. Spectral response and amplitude linearity is often quite acceptable. The noise floor is however mostly higher than that of the high-end alternatives. Van Renterghem et al. (2011) placed several types of microphones outdoors for an extended period of time to investigate their response under extreme temperatures and their aging in humid environment. The best type of consumer microphone reading deviated less than 2 dB(A) from the reference equipment over a measurement period of 6 months. A limited meteorological dependence was nevertheless observed.

MEMS[5] microphones based on micromachine technology have recently become very popular. The latest digital microphones include analog/digital conversion and even I^2S coding which allow to connect them directly to microprocessor chips. Their noise floor is quite low and impedance issues that might be caused by long wiring are avoided. Nevertheless they sometimes suffer from frost that temporary stalls correct operation.

Sound sensor nodes currently deployed commercially or semi-commercially are either based on class 2 grade microphones or consumer microphones (e.g. Libelium, Sensornet, IDEA-ASAsense). They benefit from a plug and measure design, and start measuring as soon as power is connected. If necessary, they can be managed and updated remotely.

The SmartSantander (www.smartsantander.eu) internet of things (IoT) testbed implements a large number of nodes capable of monitoring noise using Libelium (www.libelium.com) technology. Noise levels are collected together with various other parameters. A-weighting is applied to the WM-61A microphone signal using analogue electronics which makes the computational requirements on the nodes very light. As only overall levels are sampled and transmitted, light IEEE 802.15.4 devices can be used for sensing. The drawback of this technology is that only limited information can be extracted from the sound. Extensions of the SmartSantander sound sensing nodes are being developed.

The IDEA research project (http://www.idea-project.be/) and its derived technology (www.ASAsense.com) focus on maximal information extraction. For this

[5]MicroElectrical-Mechanical System

reason a more powerful single board computer (PCEngine's Alix) is chosen as the backbone of the sensor node. It is combined with a Knowles FG-23329-P07 microphone. 1/3 octave band spectra are sampled 8 times per second since this sampling rate allows to identify most sound events. These big data are stored in central databases for several months. Software agents analyse and interpret the data and store the results in a data-warehouse that can be accessed by users and third party applications. Quantities such as L_{Aeq}, statistical levels, and average spectra that are usually found on sound level meters are available, making the internet of sound observatories resemble a distributed sound level meter. In addition however, psycho-acoustic parameters such as loudness and sharpness as well as a multitude of indicators for spectral content and temporal fluctuation are made available. Finally, and most importantly, artificial neural networks identify the sounds that are most likely candidates to be noticed by a human listener that would be residing at the microphone location. This opens new opportunities for targeted sound management.

The user has to consider whether spectral information (1/3 octave bands) or even more advanced feature extraction and sound recognition are needed, keeping in mind that this might require not only a more expensive sensing device but also more power consumption and higher bandwidth. If 3G/4G has to be used, the price of data transmission may become a significant factor in the deployment of the sensor network.

Mobile measurement devices pose slightly different constraints. For use by pedestrians they should be light and as the battery is a main part of this weight, energy consumption is very important. Data transmission can often be limited to those instances where the device can connect to the internet free of charge.

2.3.4 Participatory Monitoring and Ad-Hoc Measurements Using Smartphone Applications

2.3.4.1 Use of Smartphone Microphones for Environmental Noise Monitoring

In recent years a multitude of free smartphone apps has become available that allow to measure the ambient sound level using the phone's built-in microphone. Examples include NoiseTube (Maisonneuve et al. 2010; Stevens 2012) and WideNoise—both discussed in detail below. This creates opportunities for citizens to use affordable, off-the-shelf mobile phones as tools for ad-hoc sound measurement and participatory noise monitoring campaigns.

As noted before, the accuracy requirements for large-scale noise monitoring or participatory sensing, tend to be lower than those for professional acoustic equipment. For example, in an urban context, it is not necessary to use equipment with a 20 dB noise floor. Many applications (e.g. comparing one street vs. another, or a Monday morning vs. a Saturday afternoon, etc.) typically do not require error margins of <1 dB. Moreover the cheaper equipment also creates a potential for scaling up monitoring efforts. If sufficient amounts of data are available about the same or similar times and places, then the inherent random errors caused by measurement devices of lower quality can be averaged out (Stevens 2012).

Nevertheless minimal quality requirements should of course be kept for any the collected data to be credible. D'Hondt and Stevens used the NoiseTube platform to evaluate the suitability of mobile phones and their microphones as sound level meters and to develop strategies to calibrate such devices to improve accuracy (D'Hondt et al. 2013; Stevens 2012). In the controlled environment of an anechoic chamber they exposed 11 instances of a cheap (∼100 €) feature phone model to pure tone and white noise signals to determine the they accuracy of sound level readings as measured with the NoiseTube application. After a level-dependent calibration[6] the phones performed close to being on par with a Class 2 sound level meter—at least in a laboratory environment and for white noise signals. The tested phones had a noise floor of about 30 dB and spectral responses were found to be sufficiently flat for measuring complex (i.e. multi-spectral) urban sounds at levels above 50 dB . It is plausible that the (hi-end) devices that are on the market now would perform even better, particularly in terms of spectral response (Fig. 2.3).

The influence of wind exposure on sound level measurements can be significant. However, in the case of continuous and mobile monitoring this influence could be eliminated to a large extent by averaging measurements over sufficiently long intervals of time (or space), thanks to the inherent variability of the wind itself, the changing density of urban topography, changes in walking direction, etc. Wind influence, as well as other random errors can also be eliminated by performing repeated measurements across a number of days or weeks (D'Hondt et al. 2013; Stevens 2012).

2.3.4.2 Examples of Smartphone Applications

The *NoiseTube* mobile application (Maisonneuve et al. 2010; Stevens 2012), is available for the Android, iOS and Java ME platforms and is designed with a strong focus on measurement accuracy. It supports A-weighting and can be calibrated for different phone models, or even individual devices. The app is able to automatically download calibration settings for particular phone models via the Internet. The NoiseTube app works as a continuous monitoring device, producing (and storing) geo-tagged series of L_{Aeq} measurements over 1 s intervals. Users can enrich the data by freely adding "tags" to measurements (e.g. to indicate sound sources, subjective impressions, etc.). All data can be transferred to the NoiseTube.net website where it can be shared with other users and noise maps can be generated.

[6]The calibration in NoiseTube is done by applying a level-dependent correction factor to each measurement. Details on the calibration process can be found in (Stevens 2012) and (D'Hondt et al. 2013).

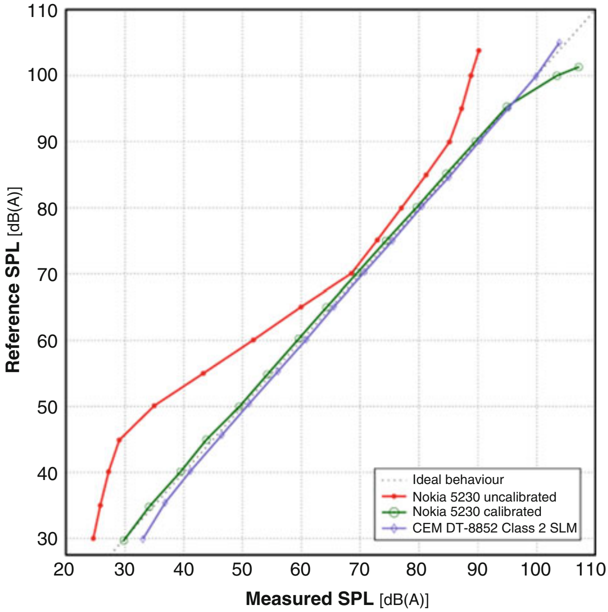

Fig. 2.3 A-weighted sound level measurements of white noise signals by an uncalibrated and a calibrated NoiseTube instance running on a Nokia 5230, and a Class 2 sound level meter [X-axis]; set against the reference levels as measured by a Class 1 acquisition station [Y-axis]. *Source* : D'Hondt et al. (2013), Stevens (2012)

D'Hondt and Stevens set-up two coordinated measuring campaigns with volunteering citizens in Antwerp (D'Hondt et al. 2013; Stevens 2012). Their evaluation covered data quality, usability and organisational aspects. Through comparison of the resulting noise maps with an official, simulation-based map, they found strong indications that support the validity (e.g. capturing expected trends) and added value (e.g. detection of noise that was underestimated by the official map) of the participatory approach, as well as its complementarity with conventional methods for the assessment of urban noise. However, all of this is dependent on rigorous campaign protocols—e.g. using calibrated devices and ensuring spatio-temporal density and overlap.

The *WideNoise* app was originally developed for the iPhone by WideTag, a mobile applications consultancy. Under impulse of the EveryAware project (www.everyaware.eu) WideNoise v3.0 introduced new features, such as the sharing of data through the EveryAware web platform, and was made available on Android as well. This version of WideNoise has been used extensively in participatory campaigns, organised in the context of EveryAware, to monitor noise and assess citizens' opinions about noise exposure (Becker et al. 2013). Widenoise is discussed in more detail in Chap. 7 of Part 1 of this book. Widenoise takes "snapshots": when the user clicks the "measure" button, the app records sound during a short interval of

5, 10 or 15 s, over which the average sound level is then computed. WideNoise does not support A-weighting and measurements are not corrected by means of device or model-specific calibration. Rather than being designed with a focus on measurement accuracy, WideNoise (v3.0) should be seen as a tool created to investigate citizen's awareness, interpretation and learning about environmental noise.

NoiseTube and WideNoise are not the only smartphones apps aimed at facilitating participatory noise mapping initiatives. Several people, often but not exclusively in academia, and sometimes in collaboration with official or non-governmental organisations, have created similar noise monitoring apps and associated web platforms for data sharing or mapping. Examples include *NoiseDroid*, *EEA NoiseWatch*, and *AirCasting*. A comprehensive overview of such initiatives, up to mid-2012, is discussed in (Stevens 2012, Sect. 6.6). At the time NoiseTube was the most complete and likely the most accurate noise monitoring solution for smartphones. It was the first to introduce social tagging, remains one of the few to support A-weighting and the only one that can be calibrated remotely via downloadable settings. However, since then, the Noisemap application, developed by the University of Darmstadt, has pushed the bar by introducing calibration in the frequency domain (NoiseTube only applies calibration in the amplitude domain) and innovative gamification and incentive mechanisms to stimulate user recruitment and retention (Schweizer et al. 2012).

In addition to apps intended for noise monitoring or mapping purposes, the major app stores (e.g. Apple's iTunes Store & Google's Play Store) also contain a wide variety of much simpler apps that claim to act as sound level meters but cannot be considered appropriate tools for monitoring purposes due to highly inaccurate readings, lack of calibration, lack of data logging and sharing features, etc.—some examples are also discussed in (Stevens 2012, Sect. 6.6).

2.3.5 Conclusion

Advances in smart monitoring and internet of things technologies in combination with the availability of cheap and reliable microphones now allow to deploy dense sound monitoring networks at an affordable cost. These networks could equally well be used in participatory sensing with people hosting sound observatories and in smart city applications deployed by authorities. In addition to fixed sensor networks, technology also allows to quickly scan an area using targeted mobile campaigns. Taking into account the richness of the information that could be extracted from the sound signal, it may be worth considering going beyond the sampling of overall A—weighted levels. This allows not only to more accurately mimic the human experience but could eventually also lead to monitoring based control of sound and other emissions.

In addition, the availability of affordable smartphones and sound level measuring and sharing apps creates opportunities for citizens to engage in participatory noise monitoring campaigns.

2.4 Closing Remarks

Current innovations in sensing technologies are leading to the development of miniaturised sensors that could be used as stand-alone devices, connected to smartphones or even embedded in smartphones. Deployment of these sensors in intelligent networks or mobile data collection during walks, bicycle or car rides could allow for widespread coverage as compared to the stationary monitoring stations.

Although there is a clear potential for involving the general public in participatory environmental monitoring, technical complexity depends very much on the parameters that are monitored. The abilities of the sensing devices significantly determine the nature and possible outcomes of such monitoring campaigns. The two parameters that were studied in detail, air quality and sound, both have a strong technological component that will determine the way sensors can be used. Several applications make use of the microphones in smart phones to carry out noise measurements. Several research groups have devoted efforts in developing devices for air quality monitoring in urban environments. However, comparatively little validated measurement results are available.

Low-cost sensors are available, but they have to be optimised for environmental monitoring. The intrinsic data quality that can be achieved, can be improved through changes in the sensor itself. But, to be successful, efforts to use sensors embedded in smartphones or to improve the intrinsic qualities of the sensors themselves have to be combined with development of flexible field calibration strategies and advanced data processing methods. Development efforts partly shift from the intrinsic quality of the measurement itself to data post-processing. In most cases there is need to integrate know-how on sensing technology, electronics, software development and data processing, based on a thorough knowledge of the parameters that are monitored.

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Chapter 3
Observing Human Activity Through Sensing

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3.1 Introduction

In this chapter we discuss new ways to observe people's activity, i.e. people's movements and whereabouts. These observations can be valuable for studying mobility, people's movement patterns through the urban environment, their use of the urban space, and finally social interaction.

Following Moore's Law, the progression in processing power is introducing technology into society at an increasing pace. Whereas smartphones at their introduction 15 years ago carried MHz processors with a few Mb of memory, current smartphones are equipped with high-end multicore processors, rich storage, multiple sensors, touch screen and different networking capabilities. The power of these devices equals that of low-end personal computers, but at a lower cost and with better portability. Their uptake has been spectacular, filling a need in our digital society. Today this means that through their phone, people continuously carry in their daily life sensors and computing power which is an important step

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towards ubiquitous computing as thought out at Xerox PARC beginning of the 1990s (Pentland 2000).

At the other end of the spectrum, low-cost, low-power and miniaturized processors are stimulating the widespread use of sensor nodes. These sensor nodes typically consist out of sensing, processing and communication modules. They can work stand-alone but their added-value comes when building networks of sensor nodes that collaborate on communication and performing tasks. As nodes do not necessarily belong to closed networks but can form a heterogeneous system of interconnected networks, this forms what is called the Internet of Things (IoT) (Atzori et al. 2010). This refers to connected devices that can observe, understand and act upon certain events without human intervention.

These technological evolutions today offer new ways for observing human behavior. In this chapter, we will look at three technologies for observation: scanning, location-enabled devices and tagging, and illustrate with examples how they can be used in travel behavior studies, in characterization of urban space or in the study of social interaction.

3.2 Observation by Scanning

Broadly speaking, by scanning technologies we refer to data measured by means of detectors that scan specific locations of interest. They are typically used for traffic monitoring where they are located along the roadside and deployed to capture roadside motorized travel behavior. Generally, these technologies can be split into two categories: intrusive and non-intrusive methods. The intrusive methods basically consist of a data recorder and a sensor placed on or under the surface. They have been employed for many years in a traffic context and the most important ones are pneumatic road tubes, piezoelectric sensors and magnetic loops. This has been widely deployed over the last decades but the implementation and maintenance costs can be expensive.

Non-intrusive methods are based on remote observations. Manual counting is the most traditional method, where trained observers gather traffic data that cannot be efficiently obtained through automated counts e.g. vehicle occupancy rate, pedestrians and vehicle classifications. In addition, other techniques have emerged based on sensing modalities like radar, infrared, ultrasound and video.

The above detectors are currently in operation for traffic count operations, where the focus lies on estimating traffic volume, possibly annotated with speed and vehicle class and aimed towards motorized transport. Mobility studies today require however a higher level of detail, giving views on (1) network connections and travel flows and (2) all users of the mobility network including pedestrians, bicyclists, public transport users. This requires not only observation of an object in a single location. It becomes necessary to follow an object over a network or site, if not completely than at least for sampled observations of its path. In this section we describe camera networks and bluetooth scanning as examples of this point-to-point scanning technology.

3.2.1 Computer Vision and Camera Networks

Closed-circuit television (CCTV) systems have known a widespread use since the 1970s with its main application in surveillance and security. During this time, the technology of video cameras and recording has known significant advances due to the evolution of sensors, computing power and digital transmission. This led among others to the migration from analogue cameras to digital technology, the utilization of the Internet Protocol (IP) for video and remote monitoring and the increased use of pan-tilt-zoom control (Kruegle 2011). On the video analytics side, better algorithms and increased computing power on the server as well as embedded on the camera has led to more intelligent applications in 2D and 3D.

Highway traffic camera systems for speeding and toll charging are based on automatic number plate reading (ANPR). These systems consist out of three processes: image capture, plate extraction and interpretation. The performance is reported to have a 90–94 % overall read accuracy under optimal conditions. Errors can be introduced due to bad calibration, bad lighting conditions, obscurity and processing ambiguity. Vehicle classification has been extensively studied for highway and urban traffic settings as reviewed by Buch et al. (2011). Most of the related works deal with the vehicle classification problem under good and steady illumination conditions. More challenging scenarios for urban settings have been studied by comparing the vehicle silhouettes against projected 3D models of several vehicle classes. Edge maps, SIFT descriptors, and region-based features are the most common methods employed in the literature to describe the vehicle appearance. In industrial traffic monitoring solutions like Honeywell and Flir, we also find vehicle classification which is often performed under more controlled conditions (e.g. camera view, observed driving) in order to simplify the processing for speed and robustness. Figure 3.1 illustrates such a system.

For machines to be able to detect, track and identify people instead of vehicles is more challenging. As people behave in a more erratic way and have much more variation in appearance, sensing of humans has long been one of the hardest machine vision problems to tackle. Success came from a combination of well-established pattern recognition techniques with an understanding of the image generation process. These methods often capitalized on regularities that are peculiar to people, as for instance human skin color which is defined on a one-dimensional manifold or the human facial geometry.

There are now several companies that sell commercial face recognition software that is capable of high-accuracy recognition with a database of over 1000 people, commercially available camera systems that perform real-time face tracking for teleconferencing, and companies like IBM, Microsoft, Mitsubishi and Sony are showing simple vision-based recognition interfaces in commercial applications. Bredereck et al. (2012) performs tracking of people in camera networks by first detecting persons using histograms of oriented gradients in each camera view and then tracking their positions with a particle filter and greedy matching. In (Morbee et al. 2010), the concept of probabilistic occupancy mapping is utilized to locate

Fig. 3.1 Example of system for vehicle counting and classification (courtesy of FLIR)

persons in each view and track/fuse using optimization techniques. Figure 3.2 shows results from Xie et al. (2012), which studies the classification of activities into three categories (sitting, standing and walking) based on the estimated trajectories of people in order to infer the position of furniture in a room. The above techniques allows face- or silhouette-based identification and tracking of people from camera to camera which scale up to the monitoring of rooms or small buildings. On larger scales (e.g. urban areas where 10,000+ people pass daily), performance will drop due to limits in recognition.

3.2.2 Bluetooth Scanning

More recently, Bluetooth has been suggested as an interesting alternative tracking technology. Since the Bluetooth protocol allows for wireless discovery and identification of nearby devices, static Bluetooth sensors placed at strategic locations can give insights into human mobility in a variety of contexts: dynamics at mass events, urban design, social studies, travel time estimation of motorized traffic (Versichele et al. 2012; Eagle and Pentland 2006).

Initially envisioned as a low-power and open protocol for implementing Wireless Personal Area Networks by Siemens in 1994, Bluetooth has since become an almost ubiquitous technology on modern mobile devices. Prior to the ability for two devices to connect wirelessly through Bluetooth, one device needs to be discovered by the

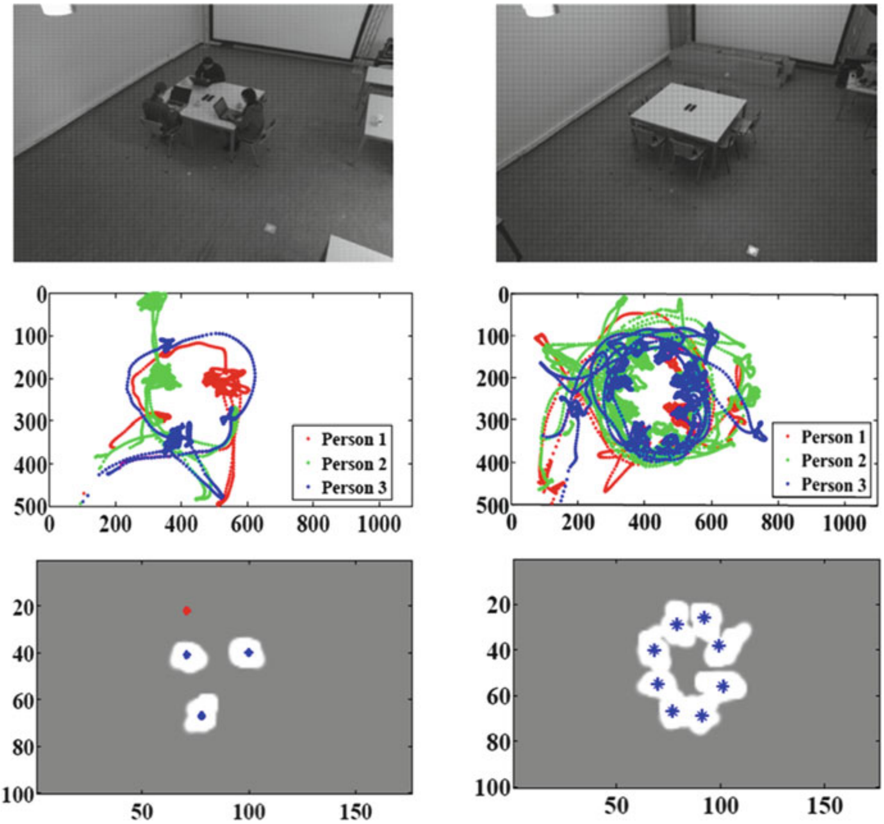

Fig. 3.2 Learning activities (sitting, walking) from observed trajectories of people and inferring the position of chairs (Xie et al. 2012)

other. This part of the Bluetooth protocol is called the inquiry phase. The master device transmits inquiry packets, to which discoverable devices within its vicinity respond with inquiry response packets. These include the MAC address (which is a 48-bit identifier of the mobile device), and the class of device (COD) code (which gives a general idea about the type of device and some of its functionalities). By mapping detected MAC addresses to a specific timestamp and location where a sensor that made the discovery was located, one can reconstruct proximity-based trajectories. Since an actual connection is not required, tracked individuals are not aware of the presence of Bluetooth sensors and the methodology is in essence completely unobtrusive. Since Bluetooth 1.2, it is also possible to register the received signal strength indicator (RSSI) of the inquiry response packets, which is loosely correlated with the distance between the sensor and the detected device.

Several studies report on the tracking of Bluetooth sensors over a study area and reconstructing movements by matching the MAC addresses of detected devices with the locations of the detecting sensors. This network-based and non-participatory approach started materializing after a first documented trial in (O'Neill et al. 2006). Since then, a growing number of experimental use-cases have been documented. Particular attention has been devoted to the use of Bluetooth technology for travel time measurements of motorized traffic as it represents a simplified approach in comparison to ANPR (Malinovskiy et al. 2010). Pedestrian mobility has also been investigated. Examples include transit time measurements in airport security checkpoints (Bullock et al. 2010), travel and dwelling time calculations in an urban context (Malinovskiy et al. 2010), and the automatic registration of public transport users (Weinzerl and Hagemann 2007). The 'Cityware' project used static Bluetooth sensors to capture mobility traces, and coupled these data with user's online social data (Kostakos et al. 2008).

An example of Bluetooth scanning for monitoring crowd behavior during large scale city events is described in (Versichele et al. 2012). Bluetooth scanning has been implemented to the Ghent Festivities event in Ghent (Belgium) in support of city event management for the organization, security, transport and emergency service providers. This event takes place on 11 squares in the city center, acting as major attractors (on-stage performances, bars and food stands, fairs). During the festivities 22 locations were covered with Bluetooth scanners, representing people's mobility within the festivity zone itself (trips from one square to another), but also the mobility to and from the festivity zone (trips to and from the two main train stations in Ghent and one park and ride facility.

Applications of the resulting data are manifold. The most direct result are the statistics about visitors and their behavior, such the number of visitors per day, the total number of visitors and unique visitors, the distribution of visitors during the day, the (sequence of) square visited by individual visitors, etc. A second, derived set of results deals with the distribution of the crowd in the festivity zone and the flows of visitors in the city center. This information is vital for security services, which are monitoring the people density in order to plan safety measures as temporary closures of access to overcrowded squares or facilitating the circulation between certain squares. This information is made available to visitors by the festivity app, assisting them to plan their day avoiding crowded routes and squares. A third set of results deals with the trip to and from the festivity zone. A smart choice of detector locations, gives insight in the modal split (train users at the train stations, car users at the park and ride facility, tram users at tram stops). Monitoring the travel times between these locations and the festival zone indicates the accessibility of the event. For example high dwelling times at the park and ride facility point to long waiting time to get onto the tram towards the city center, urging the public transport company to (temporarily) increase the capacity on this line. High travel times between the park and ride facility and the city center suggest congestion problems on the route, where traffic police should intervene to facilitate the circulation of the tram. In this way the Bluetooth scanners assist partners to optimize safety and comfort to the visitors of the festivity. In terms of data quality, care should be taken that Bluetooth scanning samples the population through the observed activity of discoverable Bluetooth devices. If absolute density or flow statistics are needed, this requires extrapolation by estimating the ratio BT versus non-BT carrying visitors at the scanner positions. These ratios can be estimating by counting the total number of visitors, either manually or automatically if possible (e.g. vehicle counting using ANPR or traffic counting loops). These are expensive processes, however the more accurate the ratios are estimated, the better the data quality.

3.3 Movement Tracking and Presence Detection Using Location-Enabled Devices

Recent technological developments have produced a range of digital tracking technologies that offer a view on the movement of users. Various technologies have been used to capture urban movement across a city, including geotagged photos, mobile phone logs, smart card records, taxi/bus GPS traces, and Bluetooth sensing (Calabrese et al. 2011a; Girardin et al. 2008; Kostakos et al. 2010; Quercia et al. 2011). Movement patterns can be used in mobility studies. It is also possible to develop a better understanding of city-dwellers' space use over time, and subsequently inform important decisions about development, growth, and investment across a city. Understanding how various groups of people move in a particular area, and when, provides better context for understanding the types of potential audiences for services in those areas, but also in terms of long-term investment and development decisions (Quercia et al. 2011).

Location accuracy and power consumption have improved by better signal processing techniques and tighter integration with various technologies (GSM, GNSS, WiFi, motion sensors). Tracking technology is currently tightly integrated with current mobile phones and personal navigation devices (PND) offering various location based services. The simple and standard solution is GNSS-based devices, carrying chipsets that receive and correlate incoming satellite signals from GPS, GLONASS and Galileo for positioning. When incorporating this data in studies on spatial human behaviour, care should be taken in the pre-processing of these data streams. Significant errors will be present due to different possible error sources: (1) poor satellite visibility or reflections (e.g. in urban canyons) leading to positional errors; (2) start up time of the GPS chip on cold start leading to several minutes of missing data at the start of the journey; (3) missing data due to memory overload or communication failure. These errors are propagated when measurements (e.g. speed, acceleration) or higher level information (e.g. trip segments) are estimated from this data. The GPS quality flags are not always a good indicator for the occurrence of these errors and care should be taken when processing the data, either by preprocessing the data (e.g. kalman filtering for data integration) or by calculating more reliable quality measures on the data.

Less known is the fact that cell communication offers other possibilities to track people continuously. Operating on a phone network requires the network operator to be able to detect the subscriber's proximity to a specific antenna, even when no calls are made. Using multilateration of radio signals between antenna masts on the cellular network and the cell phone, its location can be estimated. In general, the accuracy of tracked mobile devices is lower than GNSS-based devices, ranging from 50 to 100 m depending on the density of the cellular network. Projects like MIT's Senseable City have investigated behavior patterns through cell phone activity (Calabrese et al. 2011a). The analyzed activity is still limited to presence detection within cells of typically 100 m radius and does not take into account dynamic spatial movement patterns. Coarse-grained mobile phone traces are primarily suited for developing models for traffic estimation in some cases in real-time (Calabrese et al. 2011b), and to estimate the precision, metering frequency and the number of localizations necessary to achieve accurate traffic descriptions. The literature has demonstrated clear patterns emerging on a daily and weekly basis across a city.

In a similar way, the WiFi network can be used to locate WiFi-enabled devices within a position calibrated network as is currently offered as a service by Google in Android.

3.3.1 Monitoring Traffic with Floating Car Data

Floating car data (FCD) come from so-called probe-vehicles, i.e. vehicles that are equipped with the necessary devices to transmit data to a data center at regular time intervals. The data comprise information on the status of the vehicle, for instance its location and speed. The equipment in the probe-vehicles is typically GSM communication sending out a GNSS positioning signal. This can be a simple black box datalogger, as used in fleet management systems, or can be integrated within an internal or external navigation system in the car. In the data center, data is processed in order to make it useable. The accuracy of the derived information depends on the frequency of the positioning and broadcasting of the data, the accuracy of the GPS and the number of probe-vehicles.

The utilization of FCD has been extensively investigated in a number of papers (Asmundsdottir et al. 2010). In The Netherlands, the Ministry of Transport, Public Works and Water Management investigated the usefulness of FCD to get an understanding of the possibilities and problems. The experiment was part of a large innovation research program called "Roads to the Future". Approximately 60 vehicles in the city of Rotterdam were equipped with GPS to estimate travel times. Results indicate that the FCD system is fairly accurate and can be applied to traffic information and traffic management systems (Taale et al. 2000). Torp and Lahrmann (2005) propose a complete prototype system that uses FCD for both automatic and manual detection of queues in traffic. The automatic detection was based on analyzing GPS data from the taxis. The manual detection was based on taxi drivers reporting traffic queues by using the equipment in the taxis. Reinthaler et al. (2007) proposed a system that uses FCD to calculate detailed routes and travel times for hazardous goods transport in the Austrian road network.

FCD is used in the production and maintenance of road network databases. This production process requires a lot of work and resources which in addition needs to be in constant update. Instead of manual surveying or mobile mapping, vehicles can be used as proxy in the sense that where there are vehicles, there must be a road. Companies like TomTom, who have altered their map production process in order to receive and process anonymized GPS-data from the navigation devices of their customers. With this data, they are able to build and update their road network database. In addition to simple, static geometry, they are able to extract information on driving direction, speed limits and dynamic travel time.

3.3.2 Monitoring Dynamic, Multimodal Crowd Behaviour Through Cell Phone Localization and Activity

The introduction of GPS started an important revolution in travel behaviour studies, i.e. in the collection of trip data. By logging the tracking data, an enormous amount of detailed information on the exact position of devices became available, together with the corresponding time stamps, showing potential to fill some of the gaps that were not covered in traditional methods. However, GPS-logging has a major restriction: as devices are typically installed in vehicles, they only monitor the use of the vehicle and therefore typically cover only a unimodal part of an individual's trip behaviour.

The application of portable handheld GPS-devices offered a solution to this issue, but again required the effort and discipline from the respondent to continuously carry the device with him, as forgetting the device would result in unreported gaps in the trip data. The resulting, multimodal tracking data also introduced the new challenge of interpreting the data. In case of passive logging, where tracking is performed without additional input from the user, the survey does not include any information about trip purpose or travel mode. These characteristics can be reconstructed afterwards, either by means of additional surveys (Asakura and Hato 2004) or by interpreting the data using logical rules, e.g. using speed or GIS information (Tsui and Shalaby 2006). Splitting the continuous GPS-logging into separate trips by detecting origins and destinations is based on dwelling times at one location The determination of the travel mode is primarily based on speed characteristics during the trip, which can be complemented with additional GIS-data e.g. about public transportation networks and rail networks or accelerometer data (Hato 2010). Trip purpose can be estimated using land use maps or by analysing the individual trip chaining. Good results are achieved for determining trip ends and travel modes, but the estimation of trip purposes remains unsatisfying (Gong et al. 2011).

Smartphones bring new possibilities for tracking, having the same capabilities as the portable GPS-device but with additional sensors which can offer a more solid base for travel mode determination (accelerometer, Bluetooth, WiFi). Carrying a smartphone has also become a habit and is therefore considered less of a burden, reducing the risk of non-reported trips. Furthermore, smartphones offer the opportunity of running interactive mobile applications, where respondents can report additional trip data, e.g. on trip purpose or travel mode. Although the app requires a manual intervention by the respondent (“active” or “interactive logging”), the burden is limited because the reporting is restricted to short entries at the very moment of departure and arrival. As a consequence, time and location of the departure and arrival can be more accurately detected.

A smartphone application called CONNECT is used in Vlassenroot et al. (2013) to monitor dynamic, multimodal crowd behavior through smartphone localization and activity. In order to collect data for crowd behavior analysis, a mobile application released through the appropriate channel is installed by the user. After registration and informing the user of the purpose of data collection, this application collects different kinds of valuable information and sends it to a central server. If the smartphone contains a GPS-chip, accurate locations of the phone can be collected. However, because GPS is very demanding on the battery and does not work inside buildings, the GPS is only activated when appropriate. Other sensor information can be used to derive the location of the phone as accurately as possible, such as cell towers and WiFi. On top of that, measurements of the accelerometer of the smartphones are collected in order to automatically distinguish between different transport modes (pedestrians, cyclists and cars). Depending on the data campaign, the user can have full control over when and which data is being sent. Because of the diverse positioning modes, tracking can be done indoor as well as outdoor and the battery life can be preserved better than in standard GPS-mode. The CONNECT mobile application is shown in Fig. 3.3.

The application has two modes of operation. The first mode is a passive mode where the application runs as a data logger in the background on the smartphone.

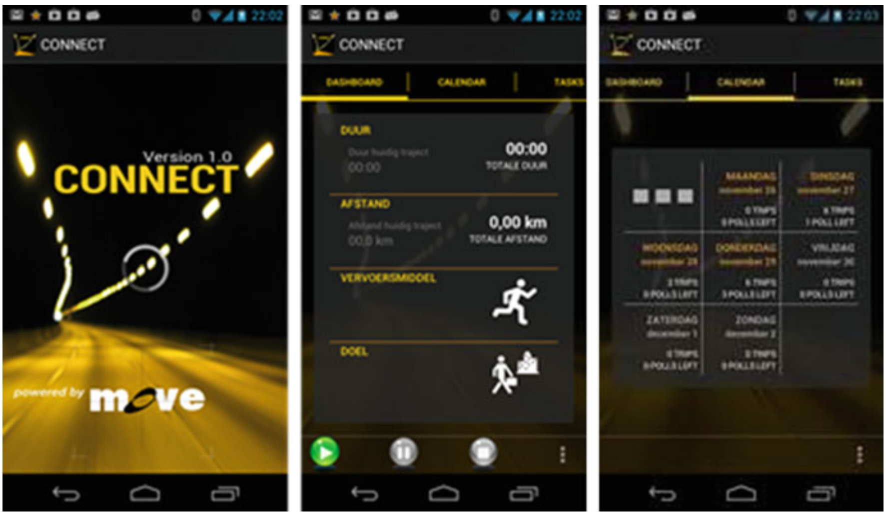

Fig. 3.3 Illustration of the CONNECT mobile application in support of mobility studies

A second mode is a diary mode aimed towards specific mobility studies. For these trials, data acquisition is done by a dedicated test audience carrying a digital diary. The same CONNECT back end is used but with a specific user interface, which additionally records activity for a given mobility study (e.g. mode of transport, aim of transport, number of passengers etc.). Data is directly transmitted to a central server, allowing realtime monitoring of the audience to see if data is generated according to data campaign guidelines (cfr. Fig. 3.4). Messages can be sent to test persons and the diary interface can be changed on-the-fly to refine or even change the study.

It has been noted that in many travel behaviour studies, respondents do not always point out the right use of mode. In order to further minimize manual input from the user, automated classification of transport mode (foot, bike, car, public transport) is very useful. On a low level, this is typically performed based on a combination of accelerometer, GPS and/or magnetometer. Table 3.1 summarizes a number of studies on transportation mode classification based on smartphone data that have been described in literature. The table summarizes the main classification results (i.e. accuracy noted under performance) and the size of the dataset used. These results show that in general satisfactory classification performance is possible, although only limited tests have been reported. The majority of methods use a combination of ACM and GPS data, and the most common preprocessing is a combination of FFT transform and simple signal properties such as signal variance. Measured ACM and GPS data are collected in batches ranging from seconds to several minutes. These

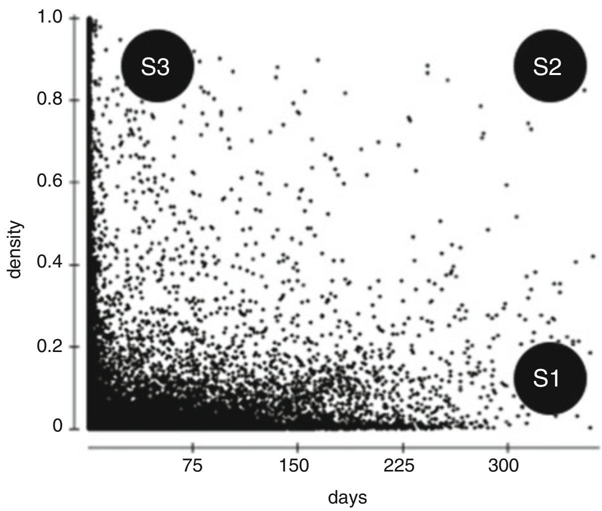

Fig. 3.4 (**a**) Distribution of individuals according to the number of unique days they used the wifi network (y-axis) vs. the timespan between the first and last time they used the network (x-axis). (**b**) Distribution of individuals according to their density, i.e. total time using the network divided by the time span between the first and last time using the network (y-axis) vs. the number of unique days they used the network (x-axis). The three visitor scenarios (S1, S2, S3) are highlighted

Table 3.1 Comparison of techniques used for automated transport mode classification

Methods used	Performance	Sensors	Preprocessing	#P	#M	References
KNN, NB, DT, SVM, CT-HMM, DHMM	98.8	ACM, GPS	FFT, variance, energy	6	8	Reddy et al. (2010)
DT	82.1	ACM, GPS	FFT, variance	1		Manzoni et al. (2010)
GDA, SVM	93.8	ACM	FFT, variance, energy, mean	3	4	Nham et al. (2008)
KMC, NB, DT, SVM, CT-HMM, DHMM	93.6	ACM, GPS	DFT+CFS	16	5	Mun et al. (2009)
DT, LR, MLP, NB, SVM	95.6	ACM	FFT	6	4	Yang et al. (2010)
DT	N/A	ACM, GPS	Variance, mean, histogram, stop rate, device usage rate			Jonsson (2010)
NB+boosting	82	ACM, GPS, magnetometer	First order statistics	1	2	Frendberg (2011)
MLP	91.2	GPS	First order statistics		3	Gonzalez et al. (2008)

GDA Gaussian discriminant analysis, *KNN* K-nearest neighbours, *NB* Naive Bayes, *DT* Decision trees, *SVM* Support vector machine, *HMM* Hidden Markov model, *KMC* K-means clustering

#P stands for the number of people involved in the trial, #M represents the number of modi to be classified batches are resampled to a uniform sampling rate and preprocessed to a frequency spectrum using fast fourier (FFT) and deriving associated frequency measures like variance and energy. Supervised classifier methods are trained using manual ground truth data.

3.3.3 Characterising Urban Space Based on Population-Level Movement: Tourist Spotting Using Wi-Fi

While in the previous paragraph people data are collected *explicitly*, here we discuss how this can be achieved *implicitly.* In this paragraph we present original work and results on characterizing urban space by considering population-level movement.

Previous work has considered population movement as a whole, or has focused on a particular subpopulation (e.g. tourists) to derive such a characterization. In the introduction to this paragraph examples using mobile phone traces were cited. An important limitation of these approaches is the coarse spatial granularity that does not allow for characterization of precise street-level locations. To achieve higher granularity, researchers are increasingly turning to alternative datasets. Analysis of user-generated content is becoming increasingly popular, for example using geo-tagged photos to extract "place" and "event" information (Rattenbury et al. 2007). Other work has considered granular Wi-Fi data (Calabrese et al. 2010; Kim and Kotz 2005) but so far limited to campus scale. Often, mobility analysis attempts to cluster locations based on similarity to each other in terms of volume of visitors. For instance, researchers have demonstrated a bottom-up approach to grouping locations into clusters that exhibit similar temporal mobility patterns in terms of volume of visits (Kim and Kotz 2005), and subsequently labels these clusters according to a tacit understanding of both the locations as well as the mobility patterns there (Calabrese et al. 2010).

Our work focuses on identifying short-term visitors to a city, and seeks to characterize urban space by contrasting these short-term visitors with long-term city-dwellers. It is expected that these two subpopulations exhibit sharp differences in their mobility patterns, because short-term visitors are new to the city and have not had time to adapt their behaviour.

This case study uses log data from a free and open municipal Wi-Fi network for the year 2010. By nature, this technology is more granular than cell phone technology, and works well for both indoor and outdoor spaces with a typical range of dozens of meters. The data originate from a network deployed in the city of Oulu, Finland, and consists of almost 1300 access points deployed in various parts of the city, but more densely in the downtown area and the university campus area. In particular, one data record exists for every time a device like a mobile phone or laptop associated or disassociated with the wireless network. In total the data consists of 7.8 million records for more than 82,000 devices, with all devices using the Wi-Fi network for a total of 200 million minutes, which is equivalent to 382 years. Finally, the population of the city (1500 km^2) is 140,000, while the broader region (37,000 km^2) has 385,000 residents.

To analyse these Wi-Fi traces one can rely on the identification of a particular segment of the population, in this case short-term visitors to the city. Previous work has shown that the use of temporal thresholds can identify visitors. For example, Girardin et al. (2008) define tourists as people whose activity is limited to a 30-day period in a city. The use of arbitrary temporal thresholds is the only way to passively identify "visitors", simply because the term "visitor" is vague. For instance, the three following scenarios exemplify diverse instances of visitors:

- Scenario S1: a person visits a city for 5 days each month of the year
- Scenario S2: a person visits a city for 2 consecutive months during the year
- Scenario S3: a person visits a city for 5 consecutive days during the year

In this study we are interested in Scenario S3, i.e. understanding how short-term visitors behave differently from others. Hence, one can use a similar but more conservative approach as Girardin et al. (2008) and choose to focus on visitors who used the network for less than 10 days during 2010.

However, an initial analysis of the data suggests that this approach to defining visitors alone can be problematic due to the intermittent nature of Wi-Fi connectivity (Kim and Kotz 2005). It is quite possible that residents who live outside the Wi-Fi coverage area only use the network sporadically, especially if their daily routine does not involve a trip downtown. In Fig. 3.4a this intuition is validated by constructing a scatterplot where each dot represents a device from the dataset. One can observe that devices that used the network for a particular number of days during 2010 greatly varied in the timespan between the first and last time they used the network. For this reason a metric of "density" is developed, defined as the total time that a device used the network divided by the timespan of the device in the dataset (the time between its first and last sighting in the data). This way Fig. 3.4b can be constructed by plotting density versus the total number of days that a device used the network. This graph is annotated by indicating where the three scenarios described above fit, indicating that short-term visitors (Scenario S3) are in the top-left quadrant in Fig. 3.4b.

The next analysis stage characterizes various locations across the city by considering the differences in urban movement between visitors and residents. An initial approach was to characterize each location based on its popularity with visitors as proposed by Girardin et al. (2008). Careful inspection of these results, however, revealed that many places that were relatively popular with visitors are also popular amongst residents. A good example is the airport: the airport, along with other busy places, is popular with both visitors and residents. This particular issue has typically been ignored by researchers, either because the analysis did not focus on multiple segments of the population (Calabrese et al. 2011b; Calabrese et al. 2010; Kostakos et al. 2010; Quercia et al. 2011) or because there was no comparison between segments of the population (Girardin et al. 2008; Kim and Kotz 2005; Rattenbury et al. 2007).

To address this issue a profile metric is developed to characterize the nature of a place by considering the relative popularity of a location with visitors and residents separately. To derive this metric one first calculates the "visitor_power" and "resident_power" of a location by normalizing the popularity of that location in relation to the most popular location for each group respectively. Then one may calculate the profile metric as *visitor_power/(visitor_power+resident_power)*, ranging between 0 ("residential" area) and 1 ("visitor" area). This metric can then be used to characterize urban locations as shown in Fig. 3.5, where the airport is now profiled as a "visitor" area. An important advantage of this approach to location characterization is that it relies on an explicitly defined notion of human behaviour (in this case short-term visitors), while previous work has aimed to cluster locations that are similar to each other while being agnostic of human behaviour (Calabrese et al. 2010; Kim and Kotz 2005).

Figure 3.5 (left) shows the results of our characterization of a downtown area. The metric accurately profiles as resident areas a downtown university building

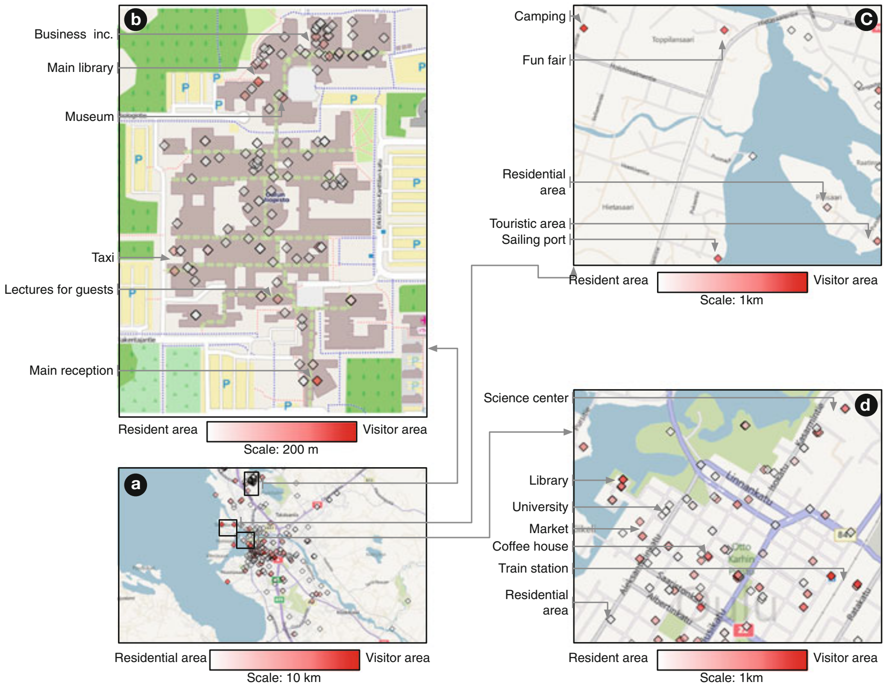

Fig. 3.5 Using the profile metric one can inspect at a very granular level the whole city, but also specific locations: (*left*) parts of downtown, (*right*) a summer destination location

where mostly students are present. On the other hand, the market and the main library are profiled as visitor areas, as well as the science centre and the train station. Figure 3.5 (right) shows that the camping, beach and fun fair areas (which mostly operate in the summer) are profiled as visitor areas. We expected this to be the case, as these are locations that are likely to attract tourists during the summer months. It is also noteworthy that the touristic area with restaurants is indeed profiled as such, despite being within 250 m of a residential neighbourhood that is also correctly profiled.

On the campus area of the University all lecture halls and research lab areas are characterized as resident, obviously due to local students and staff occupying the areas. A handful locations are identified as visitor areas, namely the main reception of the university, a taxi rank, and the hall where lectures with outside guests are held. In addition, the main library with a substantial historical archive, the museum, and the business incubator are profiled as visitor areas. The profile metric is a surprisingly accurate match to the nature of these locations concerning visitors.

The work we presented in this case study shows a way to characterize human behaviour, and a way to characterize locations, both using implicitly sensed data. Both people and location characterization can be done automatically by the infrastructure. This means that locations can e.g. automatically infer their own profile, and network providers can tailor services for users based on their profile and the profile of their location. Patterns of urban mobility have previously been shown to be crucial in our understanding of urban space, and here we show techniques for extracting these patterns in a highly localized fashion.

More importantly, the method described here allows for analyses beyond the context of short-term visitors. This case study has explicitly referred to a "profile" metric because it can be used with any segmentation of the population. Instead of considering short-term visitors, the analysis can focus on males vs. females, teenagers vs. elders, locals vs. foreigners, or any other segmentation that can be reliably captured in the data. This approach to characterizing locations by considering human behaviour can provide a new way to look at cities, communities, and behaviour over time.

3.4 Observing Encounters and Activities Using Tagging

Observing human activities using ubiquitous devices can be implemented using special sorts of tags. Bluetooth or Radio-frequency identification (RFID) tags, for example, provide cost-effective solutions for implementing sophisticated observation and tracking solutions. As outlined above, Bluetooth implemented in mobile phones provides for encounters between different devices by active scanning of the environment. The SDC Framework (Atzmueller et al. 2013) also allows to collect various physical (e.g., Bluetooth) and also virtual sensor data (e.g., for accessing online social services) on mobile Android devices, for comprehensive ubiquitous data collection, location tracking and tagging. The Find-And-Connect (Xu et al. 2011) system also utilizes Bluetooth and passive RFID for obtaining locations of participants, and infers encounters based on the co-location of participants as a proxy of contacts between participants. However, no direct face-to-face contacts are measured. Essentially, such solutions—as well as passive RFID tags—enable the tracking of participants. However, given the range of interaction of Bluetooth devices, the detected proximity does not necessarily correspond to face-to-face contacts, see (Cattuto et al. 2010). As described below, the Sociopatterns collaboration, e.g., (Barrat et al. 2010) developed an active RFID-based proximity tag for detecting close-range and face-to-face proximity (1–1.5 m) as described below. An experiment correlating RFID-based proximity data with Bluetooth-encounter data collected using the SDC Framework is described in (Atzmueller et al. 2013). Another approach for observing human activities is the Sociometric Badge (http://hd.media.mit.edu/badges). It records more details of human activities and interactions than only using the SocioPatterns RFID tags, but requires significantly larger devices compared to these tags.

3.4.1 RFID Proximity Tagging

The SocioPatterns collaboration developed an infrastructure that detects close-range and face-to-face proximity (1–1.5 m) of individuals wearing special RFID (proximity) tags with a temporal resolution of 20 s (Cattuto et al. 2010). The technical innovation of these tags is their ability to detect the proximity of other tags within a range of up to 1.5 m. Since the human body blocks RFID signals, face-to-face contacts can then be detected by tag proximity. Essentially, each proximity tag sends out two types of RFID-signals, proximity signals and tracking signals. A proximity signal is used for contact sensing, which is achieved using signals with very low radio power levels. The proximity tag further sends out tracking signals in four different signals strengths to specialized RFID readers. These tracking signals are used to transmit proximity information to a central server and for determining the position of each conference participant. Depending on the signal strength, the range of a tracking signal inside a building is up to 25 m. RFID readers measure a received signal's strength, the ID of the reporting tag and the IDs of all RFID tags in proximity. For more information about the SocioPatterns proximity tags see (Barrat et al. 2010), and the websites of SocioPatterns (http://www.sociopatterns.org) and OpenBeacon (http://www.openbeacon.org/).

3.4.2 Observing Encounters and Activities

Experience showed (Atzmueller et al. 2014) that people are more motivated to wear such tags—in particular over a longer period of days or even weeks—if they gain a personal benefit. The SocioPatterns platform has been utilized in different scenarios, for example, for tracking conference attendees (Alani et al. 2009). It was also deployed in other applications, such as healthcare environments (Isella et al. 2011), schools (Stehle et al. 2011) and museums (Cattuto et al. 2010). Barrat et al. (2010) analyze social dynamics of conferences focusing on the social activity of conference participants in those experiments. They analyze, for example, their activity in social web platforms like Facebook, Twitter and other social media together with status and their research seniority.

In addition, the SocioPatterns RFID tags are also used for the Conferator (Atzmueller et al. 2011) and MyGroup (Atzmueller et al. 2012a) systems, which enable enhanced social networking for conference participants and working groups, respectively. Both systems are built using the Ubicon software platform, see (Atzmueller et al. 2014). It aims at enhancing ubiquitous and social networking, and enables the observation of physical and social activities. For more details, we refer to Chap. 6. Conferator and MyGroup have been applied at a number of events, for example, at the LWA 2010, LWA 2011 and LWA 2012 conferences of the German association of computer science, and at the ACM Hypertext 2011.

In this context, Atzmueller et al. (2012b) analyze the interactions and dynamics of the behavior of participants at conferences. Figure 3.6 shows an example of a temporal community analysis of the LWA 2010 conference. The figure shows overlapping communities for different minimal time thresholds of the contact network ($t = 0, 1, 5, 10$) grounded by special interest groups (ABIS, IR, KDML, WM) present at the conference. The figure shows, that the communities tend to focus more on the special interest groups with an increasing minimum conversation length threshold, i.e., the communities start with a mixture of different interest groups, but concentrate more and more on special sub-communities with an increasing time threshold. The connection between research interests, roles and academic jobs of conference attendees is further analyzed in Macek et al. (2012). Furthermore, the predictability of links in face-to-face contact networks and additional factors also including online networks has been analyzed by Scholz et al. (2012, 2013).

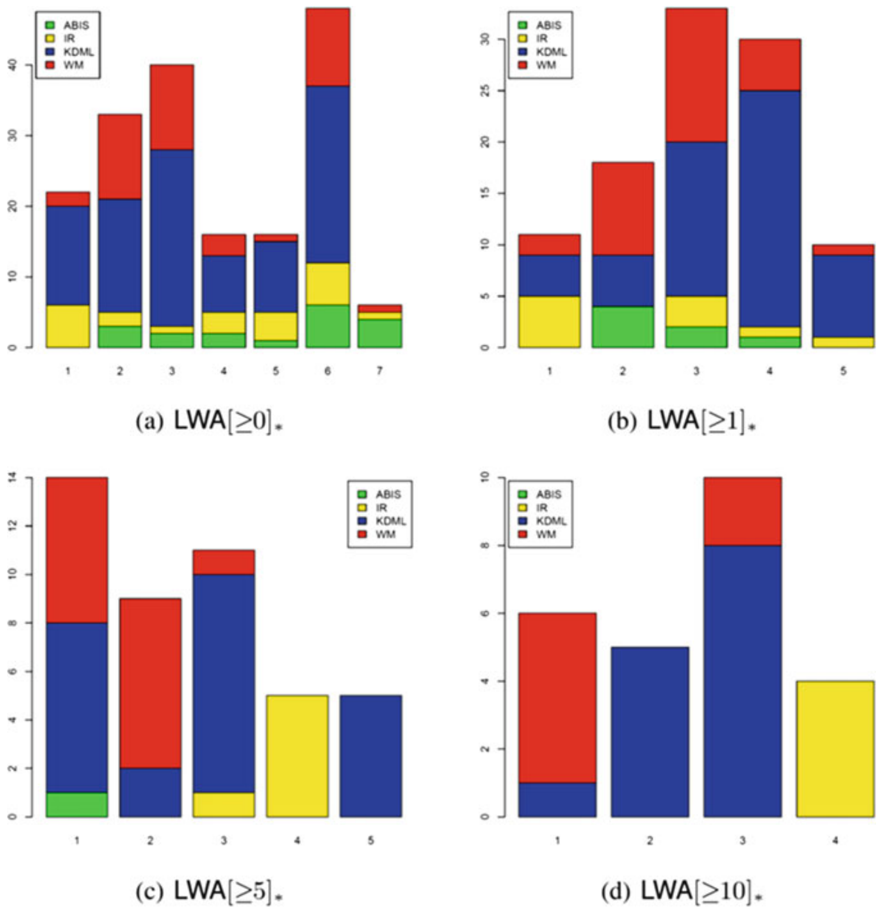

Fig. 3.6 Exemplary community detection results (overlapping communities) colored according to their special interest track distributions (Atzmueller et al. 2012). The figure shows the different special interest groups (ABIS, IR, KDML and WM). The x-axis depicts the sizes of the groups (and its subgroups, i.e., communities). From (**a**) to (**d**) the minimal conversation length threshold increases from 0 to 10 min, focusing on face-to-face contacts having at least that length

3.5 Conclusion

We have given an overview of technological solutions that allow to observe human activity. Observation by scanning, location-enabled devices and tagging have been discussed. Where smart camera networks potentially offer the most detailed analysis of human activity, the scaling of these systems to large environments currently remains limited due to the limits on the performance of the current algorithms for recognition of individuals for large databases. When observing humans outside vehicles, in multimodal transport or in indoor situations, scanning based on Bluetooth, WiFi, RFID tags or smartphones all offer a possible solution. It depends on the level of detail required, the size of the target crowd and the effort possible for activating the crowd for data generation that will determine the optimal solution for a successful data campaign.

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Chapter 4
Human Sensors

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4.1 Introduction

This chapter provides an overview of how humans can themselves act as sensors—*human sensing*—for data collection by considering a variety of scenarios. We start by providing a survey of literature, followed by proposed guidelines, and lastly discussing case studies which exemplify using humans for sensing and data collection. We present human sensing in three technical domains:

1. *Human sensors online*, where we describe how online crowd markets are enabling the aggregation of online users into working crowds, and discuss important motivation techniques and strategies for this topic.
2. *Online social media mining* on a large scale, where we exemplify how users' posting of opinions and content in online social media is enabling us to develop platforms that analyse and respond to this data in realtime. Crisis response systems are a very popular type of system in this category, and here we present an overview of many of these systems, along with a case study that focuses on one of these systems called *CrisisTracker*.
3. *Offline human sensors,* i.e. urban and in-situ systems that collect data from pedestrians. Here we provide an overview of crowdsourcing beyond the desktop, and of systems that are designed to collect opinions from pedestrians in an

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urban context. We present a case study on a set of systems that use public displays to collect feedback from citizens, and provide strategies and guidelines for conducting this kind of work.

4.2 Human Sensors Online

One way to rely on humans as sensors is to collect data from them directly. Increasingly, large numbers of online users are aggregating in online markets, like Amazon's Mechanical Turk or Crowdflower, to making themselves accessible to anyone who is interested in rewarding their time for completing some task online. Online crowd markets are generic enough, and a variety of tasks can be completed by workers in such markets, ranging from answers to surveys to writing restaurant reviews, movie reviews, annotating photographs, transcribing audio, and any other task which computers cannot reliably do at the moment—at least without training data obtained from humans first. A great example of using these online markets for sensing is *Zensors*, which enables creation of arbitrary sensors for any visually observable property (Laput et al. 2015). In practice Zensors sends images for the crowds to process and label according to clear instructions on what to look for. Using the markets, Zensors is able to produce near-instant sensor readings about the properties, and once enough data has been collected the results can be handed off to a machine learning classifier for automated sensing in future cases. These markets can indeed be an important source of collecting data from humans, but the fact that they are structured as a market (as opposed to, say Facebook) has important implications for motivating and attracting people to certain tasks.

4.2.1 Crowdsourcing Markets and Mechanical Turk

A number of crowdsourcing markets exists, with the one of most studied being Amazon's Mechanical Turk, a general marketplace for crowdsourcing where requesters can create Human Intelligence Tasks (HITs) to be completed by workers. Typical tasks include labelling objects in an image, transcribing audio, or judging the relevance of a search result, with each task normally paying a few cents (USD). Work such as image labelling can be set up in the form of HIT groups, where the task remains identical but the input data on which the work is carried out varies. Mechanical Turk provides a standardized workflow within such groups where workers are continuously offered new tasks of the same type after they complete a task within the group. Mechanical Turk also allows duplicating a HIT into multiple identical assignments, each of which must be completed by a different worker, to facilitate for instance voting or averaging schemes where multiple workers carry out the same task and the answers are aggregated.

4.2.2 Motivating Workers in Crowdsourcing Markets

It is important to provide an overview of why people take part as workers in crowdsourcing markets, and what does the theory suggest about their performance in completing tasks. A traditional "rational" economic approach to eliciting higher quality work is to increase extrinsic motivation, i.e., an employer can increase how much they pay for the completion of a task (Gibbons 1997). Some evidence from traditional labor markets supports this view: Lazear (2000) found workers to be more productive when they switched from being paid by time to being paid by piece; Hubbard and Palia (1995) found correlations between executive pay and firm performance when markets were allowed to self-regulate.

However, there is also evidence that in certain situations financial incentives may not help, or may even hurt. Such extrinsic motivations may clash with intrinsic motivations such as a workers' desire to perform the task for its own sake. This is particularly important in the context of online crowdsourcing where the "employer" does not control the working environment of workers.

For example, a classic experiment by Deci (1975) found a "crowding out" effect of external motivation: students paid to play with a puzzle later played with it less and reported less interest than those who were not paid to do so. In the workplace, performance-based rewards can be "alienating" and "dehumanizing" (Etzioni 1971). If the reward is not substantial, then performance is likely to be worse than when no reward is offered at all; insufficient monetary rewards can act as a small extrinsic motivation that tends to override the possibly larger effect of the task's likely intrinsic motivation (Gneezy and Rustichini 2000). Given that crowdsourcing markets such as Mechanical Turk tend to pay very little money and involve relatively low wages (Paolacci et al. 2010), external motivations such as increased pay may have less effect than requesters may desire. Indeed, research examining the link between financial incentives and performance in Mechanical Turk has generally found a lack of increased quality in worker output (Mason and Watts 2009). The relationship between price and quality has also had conflicting results in other crowdsourcing applications such as answer markets (Harper et al. 2008). Although paying more can get work done faster, it has not been shown to get work done better.

Another approach to getting work done better could be increasing the intrinsic motivation of the task. Under this view, if workers find the task more engaging, interesting, or worth doing in its own right, they may produce higher quality results. Unfortunately, evidence so far regarding this hypothesis has been conflicting. For example, work by Chandler and Kapelner (2013) reported that while crowdsourcing tasks framed in a meaningful context motivate individuals to do more, they are no more accurate. On the other hand, work by (Rogstadius et al. 2011a) suggests that intrinsic motivation has a significant positive effect on workers' accuracy, but not productivity.

These contradictory results and a number of other issues that suggest the question of motivating crowd workers has not yet been definitively settled. First, prior studies have methodological problems with self-selection, since workers may see equivalent tasks with different base payment or bonuses being posted either in parallel or serially. Second, very few studies besides have looked at the interaction between intrinsic and extrinsic motivations; Mason and Watts (2009) vary financial reward (extrinsic), while Chandler and Kapelner (2013) vary meaningfulness of context (intrinsic) in a fixed diminishing financial reward structure. Finally, the task used in Chandler and Kapelner (2013) resulted in very high performance levels, suggesting a possible ceiling effect on the influence of intrinsic motivation.

4.2.3 Running Experiments on Mechanical Turk

Using Mechanical Turk has posed a problem for experimental studies, since it lacks support for random participant assignment, leading to issues even with between subjects control. This is especially problematic for studies of motivation, as self-selection is an inherent aspect of a task market. This means that results in different conditions could be due to attracting different kinds of people rather than differences in the conditions themselves.

For example, given two tasks of which one pays more and one pays less, making both of them available on the site at the same time would bias the results due to the contrast effect. This contrast effect would be problematic even for non-simultaneous posting if workers saw one task at one price and then the same task at another price at a later time. If tasks were put up at different times, then different workers might be attracted (e.g., Indian workers work at different times than Americans; some days/times get more activity than others, etc.), or more attractive work could be posted by another requester during one of the conditions but not the other.

The other extreme is to host everything on the experiment server, using Mechanical Turk only as a recruitment and fulfilment host. All participants see and accept the same identical task, and are then routed to the different places according to the appropriate condition on the experimenter's side. This fails when studying how workers act naturalistically, as everything is on the host environment. Thus aspects such as the title, description, and most importantly reward cannot be varied by condition, making it impossible to study natural task selection.

For these reasons, an approach proposed by (Rogstadius et al. 2011a) was for participants to fill out a common qualification task with neutral title and description. This qualification task (for example, simply collecting demographic data) is hosted on the researcher's server (rather than Mechanical Turk), and on completion randomly assigns the participant to one of the conditions through a "condition-specific qualification" in the Mechanical Turk system. This qualification enables workers to see and select only tasks in that condition when searching for tasks in the natural MTurk interface. In their study, Rogstadius et al. (2011a) used a Mechanical Turk qualification type with six different possible values corresponding to the different conditions. The key benefit of this approach is that participants still use the Mechanical Turk interface as they naturally do to self-select tasks, which can have condition-specific titles, descriptions, content, and rewards. While participants can still explicitly search for the tasks in other conditions and see them in some HIT listings, HITs cannot be previewed without having the appropriate qualification. Hosting the task externally would avoid the explicit search problem, but would not address non-preview textual descriptions or the key issue of supporting condition-specific variations in payment.

Another advantage of the qualification-task-approach is that the worker will always retain the qualification granted to them by the experimenter (so they can be kept track of). Thus, for example if an experimenter wanted to make a new experiment available to a subset of their participants they could add the qualification for it to the appropriate participants and the task would automatically become available to the target participants on Mechanical Turk. For more intensive recruitment, once a worker has completed the qualification task and their worker ID is known, they can be emailed directly by the experimenter, even if they did not complete an experiment.

This proposed approach for recruiting participants from a crowdsourcing market lets us retain some of the control of a traditional laboratory setting, the validity of participants searching for work in their natural setting, and the benefits offered by a greater diversity of workers more representative of the online population than undergraduates would be (Horton et al. 2011). The legitimacy of doing both cognitive and social experiments with Mechanical Turk has been supported by multiple studies, e.g. (Heer and Bostock 2010; Paolacci et al. 2010).

4.2.4 Strategies and Guidelines for Crowdsourcing

A number of strategies are proposed by Rogstadius et al. (2011a) on how to conduct experiments using Mechanical Turk, which we summarise here. The importance of adequate payment on a crowdsourcing market like Mechanical Turk is crucial. For example, they report that higher paying tasks attract workers at a higher rate, and that those workers also completed more work once they showed up. This resulted in both higher and more predictable rates of progress. The effect which payment has on progress is simple: higher payment leads to quicker results. In addition to increased payment, their data showed that quicker results can be achieved by simplifying each work item, which in turn increases uptake of workers. Finally, they found that no effect of intrinsic motivation on work progress. However, uptake might be improved by highlighting intrinsic value in task captions and summaries as well.

Emphasizing the importance of the work has also been shown to have a statistically significant and consistent positive effect on quality of answers in the same study. By varying the level of intrinsic motivation they show that this effect is particularly strong at lower payment levels, with differences in accuracy of 12 and 17 % for tasks worth 0 and 3 cents respectively. This difference between conditions was even more conservative than Chandler and Kapelner (2013), who either gave workers a description of purpose or did not. These results have application to crowdsourcing charity work, suggesting that lower payment levels may produce higher quality results. It is unlikely that workers actually prefer to work for less money, thus this might suggest that intrinsic value has to be kept larger than extrinsic value for the accuracy benefits to appear. Clearly a number of other factors may also affect intrinsic motivation including social identity, goal setting, and feedback (Beenen et al. 2004; Cosley et al. 2005).

4.3 Social Media Mining

In this section we provide an overview of online *social media mining* on a large scale. These are systems that consider how users' posting of opinions and content in online social media can enable us to gain insights into unfolding events. We survey a variety of online systems that collect user contributions, and summarise a few ways in which analysis and mining of such data can be seen as a sensor of human behaviour. Finally, we focus on systems that conduct real-time analyses of such data. Crisis response systems are a very popular type of system in this category, and here we present an overview of many of these systems, along with a case study that focuses on one of these systems called *CrisisTracker*.

4.3.1 End-User Contributions as Sensor Data

The widespread availability of smartphones and high-speed connectivity has enabled a range of systems that collect a variety of different types of user contributions. Some of the most popular websites on the Internet now allow people to upload content: YouTube allows users to upload videos, Flickr hosts photographs, and Facebook allows a variety of media and additionally lets people tag this media with relevant keywords. While obviously the original purpose of this content is different, the freely accessible user generated content can be regarded and processed as sensor data, originating from end-users.

Providing a system that allows users to easily tag objects can result in a valuable repository of knowledge. For example, the Wheelmap system allows users to tag, and also search for, wheel-chair accessible places using ones phone ("Wheelmap" n.d.), and in fact research suggests that doing so influences one's own views on accessibility and disabilities (Goncalves et al. 2013b). Other systems allow users to provide location-based recommendations for restaurants or similar venues. Some examples of this include giving location-aware recommendations for restaurants (Alt et al. 2010), or even providing a real-time news report from the place in which they are (Väätäjä et al. 2011). At the same time, researchers are exploring ways in which mobile phones can enable a new empowering genre of mobile computing usage known as Citizen Science (Paulos et al. 2008). Citizen Science can be used collectively across neighborhoods and communities to enable individuals to become active participants and stakeholders. More broadly, efforts such as the OpenStreet Maps allows users to annotate publicly available maps by adding shops, streets, and landmarks that are missing from the map. Commercially-driven services such as FourSquare and Google plus allow owners of businesses to add their business to the map services, and annotate it with the various facilities it offers.

In addition, recent work has shown how technology can be used to automatically and passively generate tags. For example, one project showed how smartphones in cars can use their accelerometers collectively to find potholes and problematic road surfaces (Perttunen et al. 2011). The simple premise of this work is that all phones travelling in a car will sense a “bump” when they go over a pothole, and so a combination of GPS and accelerometer data can be used to identify such problematic locations. By deploying this simple technology on taxis, buses, or other transport vehicles that routinely travel in a city, a good portion of the street network can be surveyed relatively inexpensively.

Finally, technology in general can be used to tag our own everyday lives and events, for example using the various sensors on smartphones to tag photographs with contextual information (Qin et al. 2011), and more broadly capturing an increasing aspect of our daily routines (Nguyen et al. 2009). This new abundance of everyday information about and around us opens up several avenues for new applications and research in general. One of the popular means to refine this data into something useful, into higher-level abstractions, is to leverage machine learning.

4.3.2 Machine Learning as a Sensor

Machine learning explores algorithms to learn from and make predictions on many types of data. A typical approach is to process an initial set of training data to learn from, and then predict future events or make data-driven decisions based on the historical data. Recent advances in the analysis of the large datasets amassed online are hinting at the true potential of using these techniques as a sensor of large-scale human behaviour. The range of data collected online is ever increasing, and a number of projects demonstrate how this data can act as a sensor & predictor of human activity.

A frequent domain within which machine learning techniques are applied is Twitter. For instance, researchers have shown how a sentiment analysis of the posts made on Twitter can be used to predict the stock market (Bollen et al. 2011). A reason why this works is because Twitter acts as a repository of sentiments and moods of the society, which have also been shown to affect investors in the stock market. Therefore, sentiment analysis of Twitter feed can be used as sensor to predict stock market activity. Similarly, research has shown how an analysis of Twitter can predict how well movies perform in the box office (Rui et al. 2013). More broadly speaking, due to the ephemeral nature of Twitter communications, users' moods and tendencies appear to leave a "fingerprint" on Twitter itself, and careful analysis of this data can help in predicting real-life outcomes.

A second major source of predicting real-world outcomes is online searches. Already from 2008, researchers had shown that the search volume of influenza-related queries on Yahoo can help predict the outbreak of influenza (Polgreen et al. 2008). The same finding has been subsequently verified with the search volume of queries by Google (Dugas et al. 2012; Ginsberg et al. 2009), and more broadly research suggests that web searches can predict consumer behaviour in general (Goel et al. 2010). At an even more fundamental level, recent work showed that Google search volume correlates with the volume of pedestrian activity (Kostakos et al. 2013), meaning that spikes in the Google searches relating to names of locations, places, or organisations, correlate with spikes in the number of people who physically visit such locations.

The increasing availability of large datasets online suggests that more and more of the events happening in the real world can be predicted, or possibly understood, through a careful analysis of the online traces that our societies are generating. As we describe next, achieving a real-time analysis capability of this data can provide great benefits.

4.3.3 Realtime Mining of Social Media

Social media are used in the emergency response cycle to detect potential hazards, educate citizens, gain situation awareness, engage and mobilize local and government organizations and to engage volunteers and citizens to rebuild the environment. Users of social media at disaster time include victims, volunteers, and relief agencies. Existing systems can be loosely grouped into disaster management ("Sahana Foundation" n.d.; "VirtualAgility WorkCenter" n.d.), crowd-enabled reporting (Rogstadius et al. 2013a; "Ushahidi" n.d.) and automated information extraction (Abel et al. 2012; Cameron et al. 2012; Steinberger et al. 2013).

Sahana ("Sahana Foundation" n.d.) and VirtualAgility OPS Center (VOC) ("VirtualAgility WorkCenter" n.d.) support the emergency disaster management process with information and inventory management and collaboration support for response organizations (emergency teams, security, social workers, etc.) Such systems often integrate raw social media feeds, but typically lack capabilities for distilling and handling useful reports, and avoiding information overload when activity is exceptionally high.

The Ushahidi ("Ushahidi" n.d.) crowd-reporting platform enables curation and geo-visualization of manually submitted reports from social media sources, email and SMS. To our knowledge, it is the only system specifically designed to handle citizen reports that has been actively used in a large number of real disasters. Due to reliance on users in all information-processing stages, Ushahidi's effectiveness depends entirely on the size, coordination and motivation of crowds. The majority of the most successful deployments have been by the Standby Task Force ("Introducing the Standby Task Force" n.d.), a volunteer organisation aiming to bring together skilled individuals to remotely provide help in disaster cases, using Internet technologies. For instance, Standby Task Force has set up dedicated teams for media monitoring, translation, verification, and geolocation. This approach adapts well to needs of specific disasters, but it has proven difficult to scale processing capacity to match information inflow rates during the largest events, as was shown during the Haiti earthquake disaster ("Ushahidi Haiti Project Evaluation Final Report" n.d.).

Cameron et al. (2012) developed a system that captures location and volume of Twitter data, providing near real-time keyword search. Their system relies on a trained classifier to detect specific event types, and uses a burst detection method to provide emergency management staff with clues. Twitcident (Abel et al. 2012) is a related Twitter filtering and analysis system that improves situation awareness during small-scale crisis response, such as music festivals and factory fires. It employs classification algorithms to extract messages about very specific events, but is not built to monitor large and complex events with multiple parallel storylines. Both these systems work only with geotagged tweets, which make up around 1 % of all posted messages as of 2013.

Twitcident and the work by Cameron et al. exemplify how despite extensive research into automated classifiers for short contextual strings, classification and information extraction has proven to be significantly harder than for well-formed news articles and blog posts. Like in both of these systems, classifiers tend to be language specific and new training data is needed for each new desired label. This greatly restricts their use in the mass disaster space, where report language is not known beforehand and new report types may be sought in each new disaster.

EMM NewsBrief (n.d.) and Steinberger et al. (2013) automatically mines and clusters mainstream news media from predetermined sources in a wide range of languages, with new summaries produced every 10 min. It too relies on rule-based classifiers for meta-data, but substantial investment has been made to create such rules over a decade. Despite this great investment, it has not been extended to handle social media.

Inspired by the above system, CrisisTracker (Rogstadius et al. 2013b) was developed to enable timely use of social media as a structured information source during mass disasters. Its approach to accomplish this is by combining language-independent fast and scalable algorithms for data collection and event detection, with accurate and adaptable crowd curation. Rather than displaying only high-level statistical metrics (e.g., word clouds and line graphs) and provide search for single social media messages, CrisisTracker's clustering provides event detection, content ranking and summarization while retaining drill-down functionality to raw reports. The system is intended for use during mass disaster and conflict when organizations lack resources to fully monitor events on the ground, or when physical access to local communities is for some reason restricted.

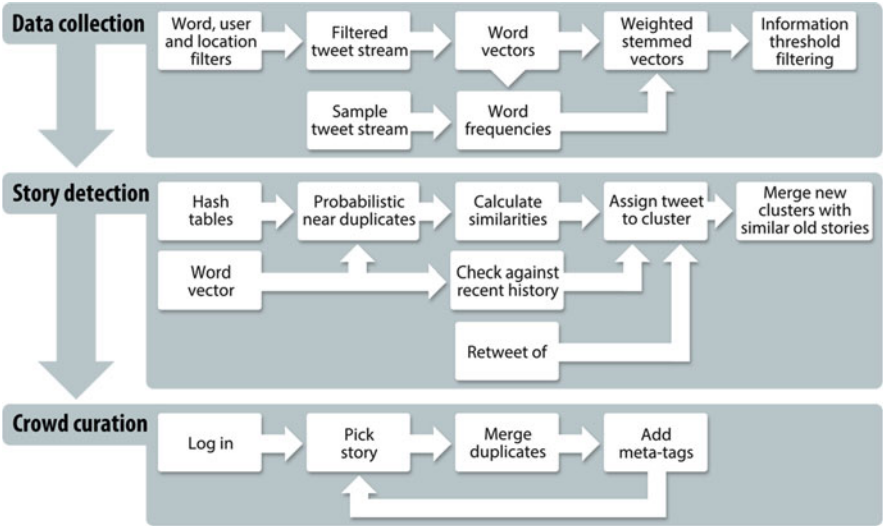

Fig. 4.1 Information processing pipeline in CrisisTracker (Rogstadius et al. 2013b)

4.3.4 Case Study: CrisisTracker

This section provides a summary of how real-time social media mining is conducted by CrisisTracker's information processing pipeline (Fig. 4.1). It consists of data collection, story detection, crowd curation and information consumption. Crowd curation is made possible by decoupling the information itself (stories) from how it has been shared in the social network (tweets). Tweets are collected through Twitter's stream API. This allows a system administrator to define filters in the form of words, geographic bounding boxes and user accounts for which all new matching tweets will be returned as a stream. Generally around 1 % of all tweets are geotagged, thus good keyword filters are the primary way to efficiently obtain information about a topic. Many tweets contain very little information and therefore the system discards messages having fewer than two words after stop word removal and a very low sum of global word weights (approximated inverse document frequencies).

4.3.4.1 Story Detection

Incoming tweets are compared to previously collected tweets using a bag-of-words approach and cosine similarity metric, to group together (cluster) messages that are highly similar. The system uses an extended version of a clustering algorithm for Twitter (Petrovic et al. 2010) based on Locality Sensitive Hashing (Charikar 2002), a probabilistic hashing technique that quickly detects near-duplicates in a stream of feature vectors. Petrovic et al. (2010) used an initial computation pass to calculate global word statistics (inverse document frequencies) in their offline corpus. In an online setting, word frequencies cannot be assumed to be constant over time, e.g. due to local changes in the tracked event and global activity in different time zones. The algorithm was therefore extended for use in CrisisTracker. Most notably, word statistics are collected based on both the filtered stream and Twitter's sample stream, i.e. a 1 % sample of all posted tweets. For a more detailed explanation on how the tweets are clustered to reflect crisis events in realtime we refer the reader to (Rogstadius et al. 2013b).

CrisisTracker's underlying algorithm offers high precision, but the set of tweets that discuss a particular topic is often split across several clusters. All new clusters are therefore compared with the current clusters to check for overlap. This cluster of clusters is called a story, and this method also enables human intervention in the clustering process. Finally, as the system would quickly run out of storage space if all content was kept, increasingly larger stories and all their content are deleted with increasing age, unless they have been tagged by a human. Stories consisting of a single tweet are kept for approximately 1 day.

4.3.4.2 Crowd Curation and Meta-Data Creation

The reason CrisisTracker clusters the tweet stream into stories is to facilitate crowd curation. De-duplication (ideally) eliminates redundant work, directly reduces the number of items to process per time unit, enables size-based ranking of stories, and groups together reports that mention the same event but contain different details necessary for piecing together a complete narrative.

Search and filtering requires meta-data for stories. Some of this meta-data is extracted automatically, i.e. time of the event (timestamp of first tweet), keywords, popular versions of the report, and number of unique users who mention the story (it's "size"). Story size enables CrisisTracker to estimate how important the message is to the community that has shared it (Rogstadius et al. 2011b). Users of the system can rank stories by their size among all Twitter users, or among the 5000 users most frequently tweeting about the disaster. Typically the top 5000 option better highlights stories with detailed incremental updates to the situation, while the full rank more frequently includes summary articles, jokes and opinions. Since meta-data is assigned per-story, it also covers future tweets in the same story.

Curators are directed towards recent and extensively shared stories, but can self-select which stories to work on. The first curation step is to further improve the clustering, by optionally merging the story with possible duplicate stories that are textually similar but fall below the threshold for automated merging. Miss-classified content can also be removed from stories, which are then annotated (Fig. 4.2) with location, deployment-specific report categories (e.g., infrastructure damage or violence) and named entities. Stories deemed irrelevant (e.g., a recipe named after a location) can be hidden, which prevents them from showing up in search results. Only a Twitter account is required to volunteer as a curator.

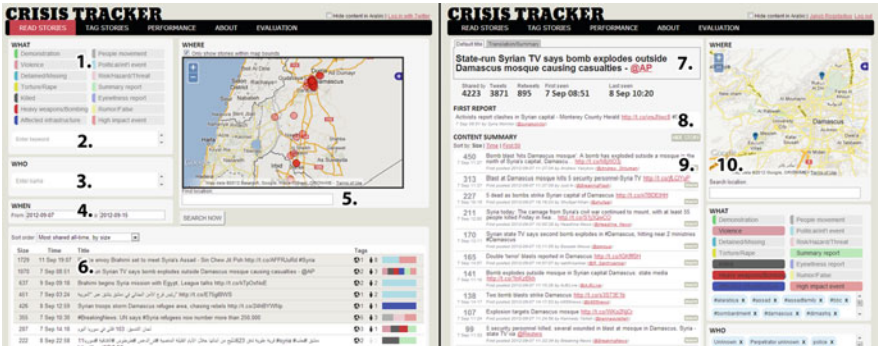

Fig. 4.2 *Left*: User interface for exploring stories, with filters for category (1), keywords (2), named entities (3), time (4) and location (5), with matching stories below (6). *Right*: A single story, with title (7), first tweet (8), grouped alternate versions (9) and human-curated tags (10)

4.3.4.3 Information Consumption

Disaster responders and others interested in the information can filter stories by time, location, report category and named entities. Disaster managers have pointed out (Rogstadius et al. 2013a) that these are basic dimensions along which information is structured in the disaster space. They match how responsibilities are typically assigned within the responder command structure, i.e. by location and/or type of event or intervention. Figure 4.2 presents the interfaces for exploring stories and for reading and curating a single story. The interface for curators to select work items is not shown.

4.3.4.4 CrisisTracker in Action

While during testing and development CrisisTracker was used to monitor events such as Fukushima nuclear disaster and various crises in Middle East, its most large-scale field trial dealt with the 2012 civil war in Syria. In the trial 48 expert curators with prior experience on working with humanitarian disasters signed up to use CrisisTracker as part of their information management toolkit. During the 8-day study CrisisTracker processed 446 000 tweets daily, on average, and managed to successfully reduce the information into consumable stories, thus helping the volunteer curators' tasks. As for concrete findings, CrisisTracker was found successful in enhancing situational awareness of such disaster areas. In practice, it took about 30 min after an isolated incident to happen before CrisisTracker could reduce the social media information overload into a consumable story. This is somewhere between direct eyewitness reports and mass media coverage. CrisisTracker is not, however, a tool to replace existing information management tools. As a research project, it still had its intended impact, as for example certain organisations of UN have specifically requested system features that CrisisTracker pioneered in this domain. Further details of the mentioned field trial are reported in (Rogstadius et al. 2013b).

4.4 Offline Human Sensors

So far our chapter has focused on collecting data from users, workers, or volunteers who typically sit in front of their desktop computer or who carry a mobile device. In this section we focus on *offline human sensors,* i.e. urban and in-situ systems that collect data from people beyond the desktop environment. We provide an overview of crowdsourcing beyond the desktop, and of systems that are designed to collect opinions from pedestrians in an urban context. We present a case study on a set of systems that use public displays to collect feedback from citizens, and provide strategies and guidelines for conducting this kind of work.

4.4.1 Crowdsourcing Beyond the Desktop

Crowdsourcing with ubiquitous technologies beyond the desktop is increasingly gaining researchers' attention (Vukovic et al. 2010), especially using mobile phones. Similarly as with online crowdsourcing, collecting on-demand information from users on the go practically allows transforming the users into human sensors, capable of providing rich type of feedback about their immediate surroundings as well as about many types of arbitrary issues.

Several mobile platforms for crowdsourcing have been suggested in academia, and quite a few exist as public and fully functional applications as well. Targeting low-end mobile phones, txtEagle (Eagle 2009) is a platform for crowdsourcing tasks specific to habitants of developing countries. Similar platforms are MobileWorks (Narula et al. 2011) and mClerk (Gupta et al. 2012) that specifically focus on asking users to convert handwritten words to typed text from a variety of vestigial dialects. Targeting smartphones, Alt et al. (2010) explore location-based crowdsourcing for distributing tasks to workers. They focus on how workers may actively perform real-world tasks for others, such as giving a real-time recommendation for a restaurant, or providing an instant weather report wherever they are. Similarly, Väätäjä et al. (2011) report a location-aware crowdsourcing platform for authoring news articles by requesting photographs or videos of certain events from its workers. Mashhadi and Capra (2011) suggest using contextual information, such as mobility, as a mechanism to ensure the quality of crowdsourced work.

A very active community has developed around the topic of crowdsourcing measurements and sensing. This participatory sensing movement is also referred to as "Citizen Science" (Paulos et al. 2008) and relies on mobilizing large parts of the population to contribute to scientific challenges via crowdsourcing. Often this involves the use of mobile phones for collecting data (Burke et al. 2006; Goncalves et al. n.d.) or even donating computational resources while the phone is idle (Arslan et al. 2012).

Despite the appeal of mobile phones, using them for crowdsourcing requires workers' *implicit* deployment, configuration and use of the device. For example, in SMS-based crowdsourcing, participants need to explicitly sign up for the service, at the cost of a text message exchange. This challenges recruitment of workers, as a number of steps need to be performed before a worker can actually start contributing using their device. For these reasons, public displays crowdsourcing has gained popularity recently, since it does not require any deployment effort from the worker to contribute.

A number of previous studies have investigated the use of public interactive displays for the purpose of collecting data, most often collecting explicit human input (Ananny and Strohecker 2009; Brignull and Rogers 2003; Hosio et al. 2012).

Opinionizer (Brignull and Rogers 2003) is a system designed and placed in two authentic social gatherings (parties) to encourage socialization and interaction. Participants could add comments to a publicly visible and shared display. During the study the authors found that a major deterrent preventing people from participating is *social embarrassment*, and suggest making the public interaction purposeful. The environment, both on and around the display, also affect the use and data collected, as the environment produces strong physical and social affordances which people can easily and unambiguously pick up on. Hence they argue for facilitating the public in its needs to rapidly develop their conceptions of the purpose of the social activity, and to be able to move seamlessly and comfortably between being an onlooker and a participant.

A further study that considered public displays as data collection mechanisms was *TextTales* (Ananny and Strohecker 2009). Here the authors attempted to explore the connection between story authorship and civic discourse by installing a large, city-scale, interactive public installation that displays a 3-by-3 grid of image-text combinations. A discussion on a certain photograph would start with SMSs sent by users, displayed in a comments stream. The comments of TexTales users deviated significantly from the "intended" topic of discourse, i.e., the theme set by the photographs. More importantly, this study highlights the challenges in harnessing the general public in natural usage settings for a tightly knit purpose.

Literature suggests that people are interested to use public display deployments (Ananny and Strohecker 2009; Brignull and Rogers 2003; Hosio et al. 2012), but with personal motives in mind resulting in strong appropriation of the technology. For these reasons, a recent study (Goncalves et al. 2013a) was the first attempt to investigate altruistic use of interactive public displays in natural usage settings as a crowdsourcing mechanism. They contrasted a non-paid crowdsourcing service on public displays against the same task being done on a Mechanical Turk (Rogstadius et al. 2011a). The results show that altruistic use, such as for crowdsourcing, is feasible on public displays, and through the controlled use of motivational design and validation check mechanisms, workers' performance can be improved.

An important difference between online crowdsourcing markets and public displays crowdsourcing is the need to login. The login mechanism on Amazon's

Mechanical Turk is a form of quality control that denies access to tasks for workers who perform poorly or attempt to cheat (Mashhadi and Capra 2011). This additional barrier is not necessary on a public display as “bad” workers have no monetary incentive to lose time trying to cheat the system. In this case, potential workers could just approach the public display and start performing tasks right away, instead of going through an authentication mechanism that would most likely greatly diminish the amount of answers gathered.

Finally, Amazon’s Mechanical Turk finds it challenging to recruit workers that speak a particular language or live in a particular city (Paolacci et al. 2010). The strategic placement of public displays could help mitigate this issue by, for example, going directly to people that speak a specific language. Another example in which public displays could be used to improve crowdsourcing capabilities would be to target a specific audience with specialized skills that might be difficult to reach otherwise. For example by placing a medical crowdsourcing task (such as the one presented in this paper) on public displays located on a medical school campus it would be possible to reach users at the exact moment when they have free time to do the tasks. In general, it seems that public displays are a highly promising medium to tap into citizens’ free time and collecting the public opinion (Hosio et al. 2014).

4.4.2 Collecting Citizen Opinions

Public display research has focused heavily on interaction, attention, and design, but relatively little attention is given to civic engagement. Civic engagement calls for understanding of functional feedback mechanisms. Previously, public displays have been proposed especially as a viable *opportunistic feedback medium* because they allow passersby to understand situated and contextually relevant information, leading to genuinely insightful feedback (Battino Viterbo et al. 2011). Supporting this, Ananny argued that public opinions are highly situated (Ananny and Strohecker, 2009) and De Cindio observed that people leave feedback often during so called *peak* or *protest moments,* when the circumstances for public discourse or disapproval are right (De Cindio et al. 2008). These results together raise the question whether situated feedback mediums could be leveraged to reach people during these key moments for discourse.

One may expect these moments to occur when citizens confront a public display in a city and are given the possibility to leave instant feedback about a locally remarkable and topical issue that invades their territory. Public displays also foster sociality and group use by nature (Kuikkaniemi et al. 2011; Peltonen et al. 2008), and getting feedback from groups of users is often easier than from individuals (Hosio et al. 2012). Furthermore, the well-known *honeypot effect*, referring to the phenomenon of people becoming interested in a display after a single individual first is seen interacting with it (Brignull and Rogers 2003), can be leveraged to our advantage in spreading awareness about the feedback channel among nearby potential users.

Archetypal feedback applications on public displays utilize typing in some form as their main input modality. Earlier, for example, Twitter has been trialed as an input mechanism for public displays. The experiments with *Discussions In Space* (Schroeter et al. 2012) highlighted especially how content about the display location itself work well for engaging audiences, and how the interfaces in uncontrolled environments must be self-explanatory and offer clear cues to users on how they can participate. Ananny and Strohecker leveraged public screens and SMS to create public opinion forums (Ananny and Strohecker 2009). Their *TexTales* installations highlighted how urban spaces can become sites for collective expression and nurture informal, often amusing discussions among its habitants.

A playful feedback application, connected to social networking services and utilizing a virtual keyboard and a web camera for feedback was introduced by Hosio et al. (2012). Studies with *Ubinion* also highlighted situated public displays being fit for acquiring contextually relevant feedback. Similar projects (Day et al. 2007; Munson et al. 2011) developed feedback systems for campus settings, utilizing online interfaces, dedicated mobile clients, and Twitter as inputs. In these studies, Twitter was suggested as a good tool to provide content for public displays, and SMS was envisioned handier for feedback than dedicated mobile applications.

4.4.3 Case Study: Opinions for Civic Engagement

We present a case study where public displays were used as a mechanism for collecting civic feedback. This was prompted by a major renovation of the city centre, which included building new pavement and underground heating systems for two of the busiest pedestrian streets in downtown Oulu, Finland. This heavily affected pedestrian flows and everyday business in all the surrounding areas, and was a heated topic in this city, and it was reported in dozens of stories in local newspapers, where it garnered heavy attention in the discussion sections both for and against the project.

In this case study, the displays used were 57″ full-HD touch screen displays with rich connectivity options, fitted in weather-proof casings. Many of the displays had been located in the vicinity of the renovation area already for several years and as such have gone beyond novelty to be an accepted part of the city infrastructure itself (Ojala et al. 2012a). The displays were on either end of each of the walking streets and one at their crossing, making them situated close to the project. Besides these five displays, at all times there were three to six more displays located elsewhere in downtown and other pivotal public spaces in the city. Figure 4.3 depicts the renovation environment and one of the displays next to the renovation area.

The tested system was an application for the public displays that allowed citizens to rate the progress of the renovation, and to provide open-ended feedback. The application was available to any member of the public in a 24/7 fashion on all displays. Civic engagement should be made available to all social groups (Mohammadi et al. 2011). Therefore, studying a system "in the wild" where

Fig. 4.3 From *left*: a conceptual image of how the new renovated street will look like (used with permission from Oulu Technical Centre), a display in the end of the same street, and the actual renovation taking place in Downtown Oulu

everyone can use is a fundamental requirement for these types of systems. This is not always easy, as the urban space itself is a rich but challenging environment to deploy pervasive infrastructure and applications (Müller et al. 2010). Several considerations, including the intertwined social practices of the area, robustness of the technology, abuse, vandalism, balance between the different stakeholders, and even weather conditions may cause constraints when deploying in the wild (Alt et al. 2011; Dalsgaard and Halskov 2010; Greenfield and Shepard 2007; Huang et al. 2007; McCullough 2004). However, to gain an understanding of how technology is received and appropriated by the general public, deployment in authentic environments, or *living laboratories,* is highly beneficial (Rogers et al. 2007; Sharp and Rehman 2005). This type of case study follows Brown's advice (Brown et al. 2011) to move beyond reporting artificial success: rather than proposing a solution that fulfils all the needs of all involved stakeholders, the study can report what happened with the chosen solutions in the complicated setting.

During the 3-month pilot, the application for providing feedback was launched 2664 times by citizens, which resulted in 81 text based feedbacks and 66 sets of likert-scale ratings. Thus, 3.0 % of all application launches led to users leaving textual feedback, and 8.0 % led to users using the smiley based mechanism. This strongly reflects *lurking* behaviour online, where up to 99 % of users do not participate in discussions, but rather follow and read information (Preece et al. 2004). The term *lurker* has an unreasonably bad connotation to it. After all, lurking is in many cases beneficial for the greater community, and a case can be even made for lurking to be normal behaviour and participation abnormal: who would be reading if everybody focused on contributing (Nonnecke and Preece 2000)?

Müller argues that public displays do not invite people for a single reason, but users come across them with no dedicated purpose (Müller et al. 2010). Further, when a display features multiple applications, many application launches are caused by curiosity or play rather than intention of using them (Hosio et al. 2010). These findings together suggest that part of the application launches was not intentional, and that if the applications were deployed on bespoke displays, the participation rate would be higher.

Several factors suggest civic engagement to be challenging. Downs has observed that citizens appear to be "rationally ignorant" of topical issues and local policies, because in their opinion the feedback they give will not be influential (Downs 1957). In this case study, the plans for the renovation were already finished and published, and it was not realistic to affect the final outcome anymore. Another consideration is target demographics. It is only fair to assume that a municipal renovation project concerns a more mature audience, i.e. taxpayers who in the end pay for it. Clary and Snyder (2002) report that it is generally harder to get feedback from an adult audience than from the young, as adults often have deeply grained habits that simply do not support community-driven participation.

However, the results of the case study remain carefully optimistic about the overall participation. While the total of 81 feedback messages (27 relevant) collected may not be a lot—especially when compared to the results of related feedback prototypes in literature—the city authorities reported it was the *only* feedback they ever received from citizens in the course of this case study. Their conventional feedback mechanisms, phone and email, were not used for citizen feedback, and they were overall very satisfied with the performance of the new feedback channel.

4.4.4 Strategies and Guidelines for Eliciting Citizen Feedback

Based on the case study described above, as well as literature, certain recommendations are presented for researchers planning to orchestrate longitudinal studies in civic engagement with public displays. First, one should expect *social use* of this technology. Social and performative uses are intrinsic factors that drive the use of public displays (Kuikkaniemi et al. 2011; O'Hara et al. 2008; Ojala et al. 2012b; Peltonen et al. 2008). This has to be considered when designing feedback applications by cultivating social use, not by trying to steer away from it. For example, Brignull and Rogers (2003) findings suggest an awkwardness and social pressure that people feel when interacting alone with public displays. Third-party stakeholders should be educated about this already early in the design phase of civic engagement installations. Hence, it is suggested to *avoid topics of civic discourse that call for participation by individuals*.

One should also s*et realistic goals* for this kind of research. It is established that various social needs, such as self-expression or ill-behaviour, present themselves in the use of new communication channels (Harper 2010; Kindberg et al. 2005; Van House 2007). If a feedback channel is deployed in the wild and allows free form submission, these needs are likely to lead to appropriation, i.e. increased amount of off-topic feedback.

Studying several related feedback applications often leads to believing that getting tens of even hundreds of feedback messages with just a few installations is technically easy (Ananny and Strohecker 2009; Battino Viterbo et al. 2011; Brignull and Rogers 2003; Hosio et al. 2012). However, common in all these prototypes is informal or amusing topics of feedback and discussion. Civic engagement, on the contrary, often has to do with narrow, predefined topic of interest to a given local authority. As such, it lacks mass-appeal (Uslaner and Brown 2005). Further, people are ignorant towards civic engagement (Downs 1957), and habits of especially adults do not support participation (Clary and Snyder 2002). When conducting research in unsupervised environments and with uncoached users, it is important to acknowledge that the participation rate may deteriorate rapidly.

It is true that perhaps controlled, situated trials could be used to elicit the same amount of feedback that this installation was capable of doing. However, sustained participation calls for longitudinal action, according to Clary and Snyder (2002), and has other benefits too. Due to its opportunistic nature, it will reach users that would otherwise be truly unreachable, as demonstrated successfully in (Hosio et al. 2012), where 67 % of the public display users had not been connected before with the corresponding authorities. The social settings, target audience, used feedback mechanisms, and the feedback topic of civic engagement all play a role in the actual and argued success of a deployment. With too high initial expectations, it will be hard to judge success later on. Hence, an important recommendation is to *be aware of what is realistic participation in a deployment in uncontrolled and authentic settings.*

4.5 Conclusion

This chapter provides an overview and multiple case studies of systems where humans are the primary source of information. Recent technological advances in making communication more affordable, computation faster, but also the changing norms regarding use of technology, have enabled a range of new applications and systems that collect data from humans. We have described how online crowdsourcing markets are enabling the collection of data from humans in a systematic way, and how harvesting of online social media can offer real-time insights into evolving events. We also provide an overview of interactive urban technologies that collect data from pedestrians in-situ.

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Chapter 5
Privacy, Trust and Incentives in Participatory Sensing

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5.1 Introduction

In this chapter, we study the socioeconomic issues that can arise in distributed computing environments such as distributed and open, participatory sensing systems. Due to the decentralized nature of such systems, they present many challenges, some of which are equally socioeconomic and technical in essence. Three such major challenges arise in participatory sensing, one economic and two social. The economic problem is centered around the provision of incentives. How can participants be provided with incentives to ensure that they contribute to the system; that they provide sensed data when requested; and take part in various sensing activities?

The social problems are related to issues of *Trust* and *Privacy*. Trust issues revolve around determining which participants send accurate and truthful data and consequently which participants could be deemed more reliable. Privacy issues revolve around the fact that participants by taking an active part in sensing campaigns, risk exposing private details about themselves, such as their location at particular points in time.

In practice all three challenges are interlinked. For example, in order to ensure participants privacy, a system could provide anonymization of the users' identity. However, given that every node/participant is anonymized, it becomes harder to put in place an effective trust mechanism, which requires the identification of both trustworthy nodes and malicious/unreliable ones. In the same vein, system designers can use incentive schemes to incentivize users to sacrifice their privacy so that an efficient trust mechanism could be put in place.

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In the rest of this chapter, we examine various approaches that have been utilized in participatory sensing projects for ensuring privacy, setting up trust mechanisms, and providing incentives. Finally, we end with a discussion that highlights the major research areas that need to be examined in more detail. We note that participatory sensing systems are related to citizen science and urban informatics, and the problems we study in this Chapter are also relevant for those fields. Therefore, our discussion here would also benefit researchers working in those fields.

5.2 Privacy

5.2.1 The Challenge of Privacy

In participatory sensing systems, data is collected and shared by the participants to satisfy the goal of the system, be it community awareness, community services, or understanding social or environmental phenomena. Inevitably, the collected measurements directly or indirectly reveal some information about the participants and their environment. If the provided data can be used to infer additional information about the participants than what they actually intend to reveal, their *privacy* is threatened.

Privacy protection can be concurrently enforced in different phases of a participatory sensing system. On the sensing devices, the users should be able to choose when, where, and with what granularity to perform sensing and reporting. Local privacy protection measures such as location obfuscation or data perturbation can be employed by the mobile nodes. On the server side, privacy protection measures such as anonymization, secure and privacy-aware storage could be put into place.

Privacy-aware data storage, processing, and visualization are crucial for implementing a complete privacy-preserving participatory sensing system. Access control, usage monitoring, and data management tools should also be provided to the participants to have a fine-grained control on *who* accesses *what* data, for *how long* and with which *granularity*. In this section we don't cover these topics in detail; a thorough review of these requirements can be found in Christin et al. (2011). Here we outline the most important privacy requirements in participatory sensing and review the privacy protection mechanisms that have been proposed in the community.

Even though individuals have different perception of privacy, it is critical to the widespread adoption and success of participatory sensing to educate the participants about the privacy implication of their participation and to develop countermeasures against possible privacy threats. Ideally, participants should be able to understand the amount of privacy protection or privacy leakage in a tangible way. They should also be provided with the tools to tune the level of their protection based on their personal preferences and the incentives they receive for contributing data. *Location* and *context* privacy protection are major privacy challenges that must be addressed to ensure privacy protection of the participants and hence the sustainability of participatory sensing systems.

In most participatory sensing applications, reports from participants have to be tagged with the location of the measurement and the time at which the measurement has been taken. However, location is private information for many people and when it is combined with time, sensitive information about habits, trajectories and relations of participants can be inferred. As stated in Johnson et al. (2007) one of the privacy challenges in participatory sensing is that participants have concerns about their context being revealed or inferred by others. For example, based on the reported data, others can discover that the participant is awake, sleeping, jogging, shopping, or in a conversation. Moreover, even social context of the participants might be inferred through the reported data. For example, if several participants attending a (private) meeting in a hotel report data, the data receiver can easily infer that they are in that hotel and in the same meeting.

Assigning sensing tasks to participants can be a threat to their privacy. For example, if user u_i is assigned a task to report temperature at location l and u_i performs the task at time t, then the creator of the task will know that user u_i has been at location l at time t. Therefore it is essential to protect privacy of participants while tasking by employing an *anonymous tasking mechanism*.

Including the identity of the user who reports data values in the reports is a clear way to disclose private information such as locations or trajectories. In order to make it difficult for an adversary to link data reports to the reporter, the reports must be *anonymized*. However, anonymization per se is not a strong measure against privacy attacks as long as the attacker can link several data reports from the same user or can analyze the reports to infer information about the user who has performed the sensing (Shin et al. 2011).

Privacy threats concern not only data providers, but also data consumers. Private information about the users who issue sensing tasks can also be inferred by adversaries. Consider a user u_i who regularly creates sensing tasks, requesting measurements of a phenomenon at a specific location l. It is easy to conclude that l is a point of interest for u_i. If the identity of u_i is known, discovering her point of interests can be a potential privacy threat. Even if the identity of u_i is not known a priori, with the help of some background knowledge it is possible to find her identity. Therefore, *queriers' privacy* is another challenge of participatory sensing that has to be addressed.

5.2.2 Privacy Protection Mechanisms

In this section we categorize the privacy protection mechanisms proposed in the literature that try to address some of the issues outlined above and give a short overview of each approach.

5.2.2.1 Privacy-Preserving Tasking

A solution proposed for privacy-preserving tasking is *task beaconing* (Johnson et al. 2007). In this approach, tasks are periodically broadcast to the users. The users who are interested in performing a task, inform the system without identifying themselves. The drawback of this approach is that no guarantees can be provided either for task completion or the quality of the results. Another proposed approach is called *attribute-based tasking* (Johnson et al. 2007). In this approach users who possess a particular set of attributes can identify themselves to the system without revealing their identities. For example, users can use cryptographic-based credentials to prove that they belong to a certain group. For instance, a user could belong to a group of users who have certain sensing modalities or have specific sensing qualities. Data integrity and quality assurance of data reports cannot be ensured in this approach due to the lack of knowledge about the identity of the users.

In AnonySense (Cornelius et al. 2008; Shin et al. 2011), privacy-preserving tasking is achieved as follows: a sensing task is created by an application and sent to the ‘Registration Authority’ (RA). RA checks the validity of the task for privacy safeness and forwards it to the Task Service (TS). The users *pull* the tasks from the TS through an anonymization network such as Tor (Dingledine et al. 2004). By using Tor, the identity and location (IP address) of users are protected when they connect to the TS. The TS verifies the tasks acceptance conditions to prevent too restrictive conditions that are vulnerable to what the authors call *narrow tasking* attacks. In narrow tasking attack, a malicious application tries to find the identity of the reporters by creating tasks with too restrictive acceptance conditions. The adversary knows that the number of users who can accept such tasks is small and consequently can discover their identity. Further, by having the users to pull tasks from the TS, what the authors call the *selective tasking* attack can also be prevented. In selective tasking attack, the adversary, who has control over TS, tries to distribute the tasks to only a few users so that their reports can be easily linked.

In certain participatory sensing campaigns, the participants query the server for data collection points (DCs), the locations for which data is required. Users generally wish to provide data for locations which are close(r) to them. However, in order to do this, users have to reveal their exact locations, and a malicious server can infer the identity of the users based on their locations, using additional background knowledge. This process is called *location-based attack*. To resolve this problem, a solution based on P2P spatial k-anonymity has been proposed (Kazemi and Shahabi 2011). Each user identifies its Voronoi cell in a distributed manner by communicating with other users. Then using multi-hop routing, each user finds at least $k-1$ other users in the neighborhood and identifies the cloaked area. However, simply sending the cloaked area along with the range query to the server does not guarantee privacy protection of the users. This is due to a special property of such participatory sensing campaigns called *all-inclusivity*, where all the participants query for their closeby locations. This property can help the malicious server to de-anonymize the users. In order to alleviate this problem, only a subset of representative queries are submitted to the server. The query results are then shared among all the users. In this approach, it is assumed that users trust each other not to reveal sensitive information about their peers.

5.2.2.2 Privacy-Preserving Reporting

As countermeasures against finding the identity of the reporter by linking data reports, several approaches have been proposed in the literature which fall into two classes: *anonymous reporting* and *location blurring*.

Anonymous Reporting

AnonySense prevents identification of the origin of the reports and the identity of the reporter by providing a mix network (MIX) for the users to send their reports to the Report Server (RS) (Cornelius et al. 2008; Shin et al. 2011). MIX acts as an anonymizing channel by routing reports through multiple servers, mixing similar reports from different sources and to different destinations, and inserting delays.

A technique called *spatial obfuscation* for privacy-preserving sensor selection has been proposed (Krause et al. 2008). In this approach, instead of selecting and contacting individual sensors, the space is divided into a set of cells and instead of individual sensors, cells are selected. Then in the selected cell, a sensor is (randomly) selected by a trusted arbitrator. Thus, the selected sensor can report its exact location and data without revealing its identity.

In order to alleviate the need of the trusted third party and for protecting location privacy and ownership privacy (i.e., associating reports to users) of the users, an algorithm called HP^3 has been proposed, which takes advantage of the social network that is formed by the participants (Hu and Shahabi 2010). Instead of uploading the report directly to the server, the user randomly chooses one of its friends and sends the report to her, which in turn forwards the report to another friend. The data is encrypted in order to prevent the intermediate nodes from exploiting the contents. To avoid data corruption, the data is segmented and redundantly sent through different routes.

In all these approaches privacy protection is achieved at the cost of more communication overhead.

Location Blurring

In order to prevent identifying the exact location of users from their reported data, the location should be blurred or should not be easily distinguishable from the location of other users. This technique is also called *spatial cloaking* and in general is achieved by *generalization* or *perturbation* of the location. In generalization, a value with higher granularity is reported instead of the actual value. In perturbation techniques, the value is replaced by a different value, e.g., by the result of a function applied to a group of values. To protect the privacy of users '*k*-anonymity concept' is widely used (Sweeney 2002). *k*-anonymity is based on the idea that from the perspective of an external observer, individuals in a group of *k* entities which share a common attribute are not distinguishable if the group is known only by that common attribute.

Even though *k*-anonymity can prevent *identity disclosure*, it is shown that it cannot prevent *attribute disclosure* (Machanavajjhala et al. 2007). Attribute disclosure refers to the case where confidential information about an individual is obtained from the semantic meaning of an attribute. *Background knowledge attack* and *homogeneity attack* are two known attacks that can lead to attribute disclosure (Machanavajjhala et al. 2007). *l*-diversity is an approach that is proposed to ameliorate privacy preservation of users (Machanavajjhala et al. 2007). The basic idea behind *l*-diversity is that each group of users (or reports) contains at least *l* well-represented values for the sensitive attributes. In the simplest case, we can say that values are well-represented if they are distinct.

In AnonySense (Kapadia et al. 2008; Shin et al. 2011) the geographical area is divided into large enough *tiles* to provide *k*-anonymity for the users. Instead of reporting their location, users report the tile in which they are located. This generalization technique is called *tessellation*. Each user knows in which tile she is located, since she can consult a pre-built tessellation map of the area. Therefore, users need not reveal their location to find out in which tile they are located.

Microaggregation technique (Domingo-Ferrer and Mateo-Sanz 2002) for anonymous location reporting is proposed in Huang et al. (2010). Microaggregation is a perturbation scheme in which users are divided into 'Equivalent classes' (ECs) and the mean of the EC represents the perturbed location of the users that form that EC. An EC is created based on the Euclidean distance between location of users and it also conforms to *k*-anonymity. That is, the number of users in each EC is at least *k*. The heuristic that is used for creating ECs is called *Variable size Maximum Distance to Average Vector* (VMDAV). The authors show that both *tessellation* and *microaggregation* have mutual advantages and propose a hybrid approach called *hybrid VMDAV* to combine these advantages. To overcome the shortcomings of *k*-anonymity, the authors employ *l*-diversity and propose LD-VMDAV, an improvement on VMDAV based on *l*-diversity.

In addition to the cloak size *k* in *k*-anonymity, it has been argued that the size of the cloaked region and the distance of the cloaks to each other are important for the privacy of users (Shokri et al. 2010). The impact of the cloak size and *k*, the size of the anonymity set, on the quality of the information has also been investigated (Rodhe et al. 2012). It has been shown that data quality is more influenced by the cloak size as compared to the size of the anonymity set.

Using *cloud-based agents* for mobile nodes and a *quadtree* which is maintained in a distributed fashion, has been proposed (Krontiris and Dimitriou 2013). The stationary agents that reside in a cloud represent mobile nodes and collaborate with each other to support location privacy without needing any third party entity that can threaten the privacy of the users. Mobile nodes send their updated locations to their agents. An agent obfuscates the location of its mobile node by choosing a region in the quadtree which best corresponds to the desired obfuscation level. The querier consults the quadtree to find the agents in the regions that overlap the queried region.

5.2.2.3 Data Perturbation

The key idea behind privacy protection through data perturbation is to add enough and appropriate noise to the data so that the data cannot be reconstructed. However, it has been shown that just adding random noise to each data item does not render reconstruction impossible because of the correlation among different data reports or between data and the context (Ganti et al. 2008). On the other hand, data which is largely perturbed is not useful for the applications. PoolView (Ganti et al. 2008) is a participatory sensing architecture with no trusted third party component in which users can locally perturb their data with application-specific noise so that data items cannot be reconstructed accurately, but the aggregate value can be computed correctly. In this approach, a priori knowledge about the characteristics of the phenomenon is required and only statistical trends about the phenomenon, such as average and standard deviation, can be reconstructed from the perturbed data reported by the participants. The noise model that is selected has to be similar to the actual phenomenon model and the distribution of the noise is a common knowledge in the community.

Another, similar idea has also been proposed for reconstruction of multidimensional data maps in vehicular participatory sensing (Pham et al. 2010). The proposed algorithm can correctly reconstruct the joint density from the perturbed data and the known noise density. This approach is shown to be effective against *filtering attack*, *range attack* and *leak attack*, but it is vulnerable against *map-based attack*. In filtering attack, the adversary uses filtering techniques to remove the additive noise from individual data. When the boundaries of the real data values and noise are finite, it is possible to find out the actual data value. This case is called range attack. In leak attack, the adversary might be able to estimate the seed of the pseudo random number generator and try to reconstruct the noise values given the noise distribution. In map-based attack, the adversary might be able to combine the real map with an estimation technique to infer the most likely trajectory.

5.2.2.4 Location Hiding and Adding Dummy Locations

In this type of privacy protection, the user does not accept sensing tasks when she is in sensitive locations. Alternatively, a user accepts tasks in long enough intervals in order to make trajectory inference more difficult. For example, in *sparse querying*, the queries to each user are imposed sparsely and infrequently (Krause et al. 2008). However, this approach cannot guarantee a high level of privacy protection if the adversary has access to enough background information about the participants. A selective hiding approach is employed in PEIR (Personal

Environmental Impact Report) (Mun et al. 2009). Users can select their sensitive locations and the algorithm creates alternative traces that are realistic but do not contain the sensitive locations. These candidate traces are further modified by time shifting and adjusting the duration of the activities so that the output is still similar to the actual output for the applications. Works like You et al. (2007), Lu et al. (2008), and Kido et al. (2005) propose to report locations from dummy trajectories which look like realistic trajectories and are also close to the real trajectories of mobile users in order to make location and trajectory inference difficult for the adversaries.

5.2.2.5 Data Aggregation

Providing aggregated data by the community to the participatory sensing system can protect the privacy of the participants. If anonymization is performed appropriately, the adversary cannot tell apart the individual contribution of participants in the aggregated report. However, in many cases, aggregated data does not satisfy the purpose of the system.

Anonygator is a distributed anonymous data aggregation service which leverages P2P aggregation (Puttaswamy et al. 2010). Each user contributes data in the from of a histogram, which is aggregated with other histograms contributed by other users in a privacy preserving manner. Anonymity is achieved through an anonymous routing scheme. Distributed aggregation is performed by using a tree-based aggregation construct which is called *multi-tree*.

The concepts of *data slicing* and *mixing* are used in Shi et al. (2010) to support statistical additive and non-additive aggregation functions. For additive aggregation functions, the key idea is that each node slices its data into $n + 1$ slices. Then, it randomly chooses n nodes, called its *cover nodes*, from its neighborhood and sends each slice to one of them. Each node sends to the aggregation server (AS) the sum of its left slice and the slices received form other nodes. In this way, the aggregation server cannot find out the individual data and its origin. Non-additive aggregation functions, such as Max/Min, Median, Histogram, and Percentile are supported by enabling the possibility of answering *count queries* in a privacy preserving manner. The basic idea is that the AS asks queries to the nodes which have "yes" (1) or "no" (0) answers. The sum of the "yes" answers is reported to the AS as outlined for additive aggregation functions. Similar to binary search, adapted queries are successively asked until the desired answer is found. This approach can protect privacy of the users unless when all other users and the AS conspire. However, intermediate nodes can make inferences about their neighbors or the whole network. In addition, the authenticity of the data cannot be guaranteed as the intermediate nodes can modify the slices they have received from other nodes.

The work in Erfani et al. (2013) tries to mitigate the shortcomings of the approach in Shi et al. (2010). The aggregator and the mobile nodes are assumed to be untrusted. Nodes can act maliciously by trying to infer measurements from their neighbors or by manipulating the aggregated data. The idea is based on additive homomorphic encryption used in secret perturbation (Castelluccia et al. 2005), and data splitting (He et al. 2007). The scheme work as follows: when a node sn_i receives a query, it generates a random key $\widetilde{K_i}$ and encodes its measurement D_i using that key and sends it directly to the AS. The random key is then transmitted to the AS via n randomly chosen cover nodes as $\widetilde{K_i} = \sum_{j=1}^{n} \tilde{k}_{i,j}$, using the random slicing technique. The AS can check the integrity of the data using the proposed secure *homomorphic MAC*.

5.2.2.6 Encrypted Data Reporting

PEPSI (Privacy-Enhanced Participatory Sensing Infrastructure) is a privacy preserving data reporting and querying approach based on Identity-Based encryption (De Cristofaro and Soriente 2011). The key idea is that each data type corresponds to a label and the labels requested in a query or provided by a participant as data reports identify the query and the reports. Upon registration, each mobile node receives an ID corresponding to the type of data of its reports and a token for allowing it to announce data. Upon query registration, the querier obtains a private decryption key that corresponds to the ID of the query. Mobile nodes upload to the Service Provider (SP) their data reports encrypted using the public keys corresponding to their IDs. Finally, SP *blindly* matches the encrypted data reports to the encrypted queries. In this way, only the registered queries for a specific type of data reports can decrypt and see the information in the reports. The major drawback of this approach is that all the types of data should be associated with a label. However, if fine-grained locations are needed, this approach does not provide location privacy as it is easy to obtain location information from the labels used by the queriers and mobile nodes.

5.2.2.7 Privacy-Preserving Querying

A simple approach for protecting privacy of a querier is to introduce some *dummy query targets* along with the real query targets. However, this approach requires more resources.

The afore-mentioned PEPSI mechanism (De Cristofaro and Soriente 2011) also provides querier privacy by allowing the querier to encrypt the query. Neither the Service Provider nor data providers can identify the real identities of the queriers. A privacy enhancing protocol for participatory sensing (PEPPeR) is proposed with the aim of protecting privacy of the queriers (Dimitriou et al. 2012). In this work, queriers directly contact the data providing node and don't have to trust the service provider. The querier first obtains a token from the service provider without revealing its identity. Then it directly contacts the mobile nodes who can answer the query. The mobile node validates the token and then serves the query. Following this protocol and by using appropriate cryptographic mechanism, querier's privacy is assured and misuse of the tokens is detected.

5.3 Trust and Reputation

5.3.1 The Problem of Trust

Due to the openness nature of participatory sensing, data with different qualities can be contributed. It is crucial to the success of the participatory sensing systems to assess the quality of the reported data and to devise mechanisms that take into account the quality while analyzing the data. For example, in order to obtain a more accurate outcome while computing the average value of a phenomenon over a region, lower weights can be assigned to the data with lower quality. The quality of a sensor reading can be specified by a value, called *trust score*, which takes values in [0, 1]. Trust scores of data reported by a person or device can depend on the *reputation* of that person or device and vice versa. This means that, in the absence of certainty about the match of the reported data to the ground truth, past behavior of a person captured by her reputation plays an important role in assessing the trustworthiness of the data.

Trust score of a sensor reading is the level of confidence in how close the reading is to the (usually unavailable) true value. Trust of a sensing report *r*, is defined in Wang et al. (2011) as the probability of *r* being correct from the perception of the receiver. Reputation of a person is the opinion of others about the actions of that person. Reputation of a sensing node is defined in Wang et al. (2011) as a global value that synthesizes the correctness probability of the past sensing reports made by the node. Therefore, trust and reputation are two different concepts, even though they have been used interchangeably.

Several sources of quality distortion can be identified in a typical participatory sensing system: (1) sensor malfunctioning due to various reasons such as calibration problems, (2) using low-quality sensors, (3) position of the sensing device that affects the level of the exposure to the phenomenon, (4) perturbation by privacy protection mechanisms, and (5) malicious behavior of the participants.

Quality assessment in participatory sensing is a challenging task. This is due to the lack of access to the ground truth or supporting evidence in many situations or the subjective view about the desired quality. Reputation systems and trust assessment have been studied in wireless sensor network domain (e.g., Ganeriwal et al. 2008; Lim et al. 2010; Yu et al. 2012). However, the unique characteristics of participatory sensing, such as human involvement, necessitates more adapted approaches.

5.3.2 Trust Assessment Mechanisms

The existing work in the area of trust and reputation management in participatory sensing can be classified in three major groups. *Reputation-based recruitment* approaches aim for recruiting participants based on their reputation computed from their past behavior in order to achieve better results for the campaign. *Privacy-aware trust and reputation management* approaches aim at providing frameworks for assessing trustworthiness of the contributions while protecting participants' privacy even though these two goals naturally contradict each other. *Privacy-oblivious trust and reputation management* methods provide trust assessment frameworks without taking into account privacy of the participants. Next, we discuss all three in more detail.

5.3.2.1 Reputation-Based Recruitment

A recruitment framework for participatory sensing has been proposed that is composed of three steps: *qualification*, *assessment*, and *progress review* (Reddy et al. 2010). In the qualification step, the minimum participation requirements such as availability, transport mode, and reputation identify the candidate participants. Recruitment is done in the assessment stage where based on some criteria such as maximizing coverage or minimizing budget, the participants are selected. Finally, the progress review continually evaluates the reputation and coverage of the participants to ensure that they are not significantly diverting from their base profile. The Beta distribution is used to calculate the reputation scores of the participants which can also incorporate aging factor.

Another reputation framework for participatory sensing is proposed in Yang et al. (2011). In this framework, reputation is a weighted sum of three factors: (1) *direct reputation*, which is calculated based on participant's past behavior and data report qualities; (2) *personal information*, including personal and device capabilities; and (3) *indirect reputation*, which includes community and organizer's trust in the participant. Based on the quality requirement specifications, participants are classified in four categories, namely, *very trustworthy*, *trustworthy*, *untrustworthy*, and *very untrustworthy*. Depending on the recruiter's criteria, participants can be recruited from these categories.

A reputation framework for *social participatory sensing* is proposed in Amintoosi and Kanhere (2013). In a social participatory sensing, existing online social networks are used as the underlying infrastructure and participants can be identified and recruited based on friendship relations. Only one-hop friends are selected as participants. The trust scores of the participants are calculated based on the quality of contributed data and the trust of participants (ToP). ToP consists of *personal factors*, such as expertise, timeliness, and locality (being local to the region of the sensing task), and *social factors* such as friendship duration and interaction time. A fuzzy inference system combines these two factors and produces a trust score for each contribution. Based on these trust scores a reputation score is calculated for each participant using the PageRank algorithm. This framework is further extended in Amintoosi and Kanhere (2013) to enable selection of friends of friends for recruitment and hence to expand the pool of participants.

5.3.2.2 Privacy-Oblivious Trust and Reputation Management

In the context of sensor networks, a reputation framework for dealing with faulty sensor readings is proposed in Ganeriwal et al. (2008). The framework consists of two components, namely a *watchdog* component and a *reputation* component. The watchdog component is responsible for detecting faulty readings based on outlier detection methods and providing the reputation component with the status of each reading. The reputation component maintains a reputation score for each sensor and updates this score based on the input from the watchdog component. Based on this approach, a reputation system for participatory sensing has been proposed (Huang et al. 2010). The space and time are divided into grids and the redundancy in each grid is used in the watchdog component to calculate a *cooperative rating* for each reading using an outlier detection algorithm. The cooperative ratings in the current epoch are then fed to the reputation component, which also uses the past cooperative ratings of the sensors to update their reputation scores. Reputation scores are computed using the Gompertz function that satisfies gradual trust build up for honest behavior and rapid trust tear down for untrustworthy behavior.

Trusted Platform Module (TPM) hardware can be used to ensure that the data reported by the mobile node is indeed the data that is measured by the sensor (Dua et al. 2009). However, this assurance does not always satisfy trust requirements and also it can threaten privacy of the users. Moreover, this technique does not prevent malicious or inadvertent behavior. For example, the user can put the sensing device in a place where the phenomenon cannot be correctly measured (e.g., putting the temperature sensor in the fridge). In many applications sending trusted raw data to the server is expensive in terms of resources. For instance, sending raw sound and video consumes too much bandwidth and one should process them before transmission to reduce their size. Therefore mechanisms are needed to ensure trustworthiness of the data not only after sensing but also after processing and transformation by third party applications (Gilbert et al. 2010). For protecting privacy of users, two platform features are provided in Gilbert et al. (2010): (1) preventing applications from accessing local resources without authorization; and (2) monitoring applications for making sure they do not release private information.

5.3.2.3 Privacy-Aware Trust and Reputation Management

A drawback of approaches such as the ones presented by Huang et al. (2010) is that for computing reputation scores, the history of user behavior is required. However, in a system that uses pseudonyms for protecting privacy of users, different contributions of a user cannot be linked together. A trusted third party that performs anonymization can be used to compute reputation scores (Huang et al. 2012), since this entity knows the real identity behind the pseudonyms. Yet, naively transferring reputation information to the applications can inadvertently help an adversary to link the reputation information to the anonymized users. In order to avoid this threat, (Huang et al. 2012) uses a *k*-anonymity scheme that ensures that at least *k* users have the same reputation scores at the same time. Christin et al. (2013) further enhances the robustness of the privacy-aware reputation mechanism, by allowing the users to periodically change their pseudonyms and apply blind signatures (Chaum 1983) to prevent linking pseudonyms by the reputation and pseudonym manager (corresponding to the trusted third party in Huang et al. (2012)). In order to reduce the risk of inferring the true identities while reputation scores are transferred from the current pseudonym to the next one, users *cloak* their reputation score. In this way, users can achieve more anonymity protection at the cost of reducing their reputation.

Blind signature mechanism is also used in Wang et al. (2013) for enabling anonymous reputation. This framework consists of three components: *provenance model*, *sensing report trust assessment*, and *anonymous reputation management*. Provenance is the meta-data that describes the origin of the data and is composed of *user provenance* and *contextual provenance*. User provenance contains the pseudonym and the certified reputation level of the user, while contextual provenance includes the sensing environment factors such as time, location, traveling mode, and sensing mode (e.g., text, image, video). Trust of a sensing report is calculated considering the reputation level of the user, and the contextual provenance of the report, as well as the similarity to the other existing reports for the same task. Similarly to Christin et al. (2013), the blind signature mechanism is used to update the reputation level of users, based on the feedback from sensing report trust calculation, without the need to reveal their actual identity.

Collaborative path hiding is an approach for protecting location privacy of participants, in which participants exchange their reports upon meeting each other and then they submit the exchanged reports. Consequently, the application server cannot link the reports to the reporter. TrustMeter is a scheme proposed to evaluate the degree of collaboration and also to identify malicious users (Christin et al. 2012). Users give feedback about each other, to the application server, without revealing any private information about the peers, regarding how many of the exchanged reports have been transmitted by the peers.

In a participatory sensing setting where participants ask the server for the closest data collection points to them, the problem of location privacy and trust in collected data is slightly different. A privacy protection mechanism called PiRi is proposed in Kazemi and Shahabi (2011) for this setting. In order to ensure trustworthiness of the contributed data while using PiRi as the privacy protection mechanism, a solution has been proposed based on redundant allocation of data collection point to users assuming that the majority of users are truthful (Kazemi and Shahabi 2012).

5.4 Participatory Incentives

5.4.1 The Question of Incentives

Distributed systems, in which participants/nodes interact freely without any centralized authority require robust incentives to ensure contribution. Since crowdsensing/participatory sensing systems are also not owned by anyone in particular, they too require the provision of social and economic incentives for participants. In the last Chapter, the question of incentives was briefly touched upon, limited to the provision of incentives for users to do high quality work. However, the provision of incentives can be used to achieve a host of goals, including incentives for adherence to the protocol; abstention from malicious activities; and contribution of resources. Furthermore, most existing incentive schemes do not depend on *financial* rewards, due to the problems identified in the previous chapter *(Motivating workers in crowdsourcing markets)* plus some additional issues that we explicate next.

The design of such incentive schemes could be guided by various approaches, including mechanism design, heterodox economics, and other socially inspired mechanisms.

Usually, incentive schemes are developed with a particular model of user-behavior in the background, which is the rational model. We first concentrate on such works because they are pre-dominant in the literature.

Certain works bring up the conflict between fairness and social welfare. Fairness can be loosely defined as the provision of best quality or highest utility to the participant who contributes the most. Social Welfare is described as the increase in the overall utility of all users.

LiveCompare is a system that allows participants to hunt for bargains in grocery shopping via participatory sensing using mobile phone cameras (Deng and Cox 2009). It uses barcode decoding for the automatic identification of grocery products, and also localization techniques for accurately spotting store locations.

In order to incentivize users to contribute, it uses a very clever incentive mechanism, which is built into the user's query for services. When a user goes to a grocery store and wants to compare prices of particular items in other grocery stores, she submits her query by taking a photograph of the item in question. This includes the unique UPC barcode. The location of the store is also sent as part of the query. So the server is able to enrich its database with pricing and location information of the particular product; information that other participants can later make use of.

A purely game-theoretical approach for incentivizing people to contribute in participatory sensing has been proposed (Luo and Tham 2012). Using a rational actor model, the system links users demands to their contributions, i.e., quality of service for particular demand is related to users contributions. Two approaches are considered: one which focuses on ensuring fairness, as in providing best service to the highest contributors; and the second approach which ensures maximum social welfare. It is proved that the solution is a Nash Equilibrium.

SenseUtil is a system in which consumers have to pay producers to carry out sensing jobs (Thepvilojanapong et al. 2013). Using principles from microeconomics, the sensed data is valued by supply and demand. Demand and supply depend on factors such as location, user's preference, type of data required, etc.

An auction mechanism for incentivizing participation has also been presented (Jaimes et al. 2012). Similarly, monetary incentives in order to increase users participation have been put forward (Krontiris and Albers 2012). It is noted that providing monetary incentives is problematic because it is hard to determine the price at which users would want to sell their data. In order to solve this problem, a reverse auction mechanism to determine the value of sensed data is introduced. The novel point in this approach is that the auction is multi-attributive to accommodate the fact that different sensing data could be of different quality. The proposal helps users select and buy the highest quality sensed data (thus implicitly providing incentives for all data providers to improve their quality).

A credit based scheme in which users earn credit by contributing data has also been employed to offer incentives (Li and Cao 2013). The system uses a 'Trusted Third Party' to ensure that contributed data is not revealed, and privacy is protected.

In order to stimulate user participation, Reverse Auction based Dynamic Price (RADP) uses a bidding system where users can sell their sensing data to a service provider (Lee and Hoh 2010). The system uses the rational user model. The aim is to minimize the cost while incentivizing users to remain in, and not drop out of, participatory sensing applications.

An incentive scheme has also been proposed for road traffic prediction system based on participatory sensing (Lan and Wang 2013). It employs a credit based scheme earlier used in other participatory systems as well (Mawji and Hassanein 2008). Users earn virtual credits when they upload their data, and when they want to avail the service i.e., they want to know the future traffic condition, they have to spend credits.

The above works relied on a rational use model and/or purely game-theoretic approaches. However, it is likely that users that take part in participatory communities have unequal resources and also exhibit different behavior. Borrowing from Axelrod and Hamilton (1981), we can assume that user behavior can simply reflect standard operating procedures, rules of thumb, instincts, habits, or imitation, etc. Furthermore, for a tractable analysis of complex behavior, a game-theoretic approach requires a high level of abstraction of the design space. It follows that different designers can choose different abstractions to reach equally valid but different (sometimes contradictory) results. Thus, it is worthwhile to model a wide variety of user behavior and study the effects of different models on the underlying incentive scheme. Agent based modeling (or simulation-based) approaches can aid designers in complementing game-theoretic approaches to explore the design space of behavioral space more comprehensively.

In line with this thinking, *NoiseMap*, a participatory sensing application used to accurately measure noise levels, proposes different kinds of incentive schemes to motivate user participation (Schweizer et al. 2012). In this mechanism, *External Incentives* work by showing users each others performance via ranking. The basic idea behind this is that competition with, and emulation of, others is a big psychological motivator for human beings. Therefore, if each user could see her performance rank in the global rankings, she could be incentivized to perform better. The ranking is available as daily, weekly, monthly and total, giving new users a chance to claim top spots fast. This is an example of *gamification* and can make the users feel excited and happy.

Furthermore, an *Internal Incentives* scheme has also been proposed, which allows users to get complete feedback on their measurement history including number of measurements taken, time spent with the application etc. There is also a scale reflecting at what time the application is used. By looking at their history users can evaluate the time and effort put into NoiseMap and set new goals for themselves.

'Top of the Worlds' is another incentive scheme not based on the rational model, which seeks to improve motivation to participate in sensing services by showing rankings in multidimensional hierarchical sets (Kawasaki et al. 2012). It is noted that previously proposed methods only rank a user among all other users, and this means that many people have little chance of being ranked in the top group, resulting in little motivation to continue. 'Top of Worlds' creates many sets with varying granularity to increase the chance of many users being ranked high. Subsequently, these rankings are presented to the users to incentivize more participation.

5.4.2 Empirical Observations

While the above are models that need to be implemented to see what effects they might have, some researchers have carried out projects in the field to explore the incentivizing models and choices that can make an impact on people's behavior. For instance, Reddy et al. carried out a project to learn more about sustainability practices at a university (Reddy et al. 2010). Study campaigns documenting use of various resources were carried out. Their findings include: (a) participants desired mobile visualizations to motivate them to participate more effectively; (b) participants were willing to accommodate minor diversions to their daily routines to help with the data collection campaign. However, they stated that drastic changes would require extra incentives; and (c) finally, participants felt that daily contribution summaries and reminders would foster increased participation.

In another work by the same authors, micro-payment system as an incentive model in an actual case study is analyzed (Reddy et al. 2010). Their findings include: (a) monetary incentives were more beneficial when combined with other motivating factors such as altruism or competitiveness (self or with others); and (b) micro-payments based on competition might be better suited for short bursty data collections unless mechanisms are added to offset participant fatigue. Making the incentive payment fair for all participants was important—very low baseline micro-payments discouraged individuals even when the potential to earn money existed.

Also, if properly designed, micro-payments have the potential to extend participant coverage both spatially and temporally.

5.5 Discussion

In this Chapter, we studied the major economic and social challenges faced by open distributed systems, such as Participatory Sensing systems. These are primarily related to Privacy and Trust on the social front, and provision of Incentives on the economic front. We have reviewed the state of the art techniques that have been proposed to address these challenges.

In this section, we will discuss three key challenges that the research community needs to address for designing successful participatory sensing systems.

5.5.1 Trusted Third Parties: Can They Be Eliminated?

A major differentiating factor in existing participatory sensing system architectures is the presence (or lack thereof) of one or more components that are fully trusted by the participants.

AnonySense (discussed in Sect. 5.2.2) architecture includes two components that are assumed to be trusted by mobile nodes, namely the *Registration Authority* and the *Anonymization Service*. A trusted third party, which is called *Anonymization Server (AS)*, is assumed to be present for creating equivalent classes in Huang et al. (2010). However, the authors propose a location perturbation approach to relax the assumption of full trust in AS. Anonygator uses a trusted entity called the *bank* for accounting and preventing malicious users from injecting disproportionate amount of false data (Puttaswamy et al. 2010). In addition, a P2P communication is assumed among participants.

PoolView does not assume the existence of any trusted third party (Ganti et al. 2008). The implication of this assumption and the approach proposed based on that, is that only aggregate community trends can be measured—not the actual value of the phenomenon sensed by the community. PEPSI (De Cristofaro and Soriente 2011) proposes a more realistic architecture composed of mobile nodes, queriers, network operator that provides GSM or 3G, registration authority, and service provider. No trusted third party is considered in the architecture. However, registration authority is an entity that has to be trusted for providing authorization and certificates. Hu and Shahabi (2010) proposes a node to node communication in a social network structure created by friendship relations among users. Therefore, no trusted third party is needed. However, for security and integrity purposes, an entity is required to issue certifications. Kazemi and Shahabi (2011) assumes P2P communication among users (*collaboration*) and therefore, the need for a trusted third party is eliminated. Another proposal suggests using cloud-based agents for mobile nodes to eliminate the need of a trusted entity and the P2P communication among mobile nodes, which is not always possible (Krontiris and Dimitriou 2013).

It can be concluded that in all the works mentioned above, regardless of the architecture, some sort of trust between entities has to be present. However, the P2P communication among users does not seem realistic. The reason is that most of the existing participatory sensing systems rely on participants carrying smartphones with Internet connectivity provided by their network operator (3G or GSM). Moreover, it is not a realistic assumption that the participants always have access to wireless access points or other network media. Finally, it is not clear if smartphone users are open to directly communicate with other users because of the lack of trust.

5.5.2 Interdependency Among Trust, Privacy, and Incentives

Privacy and trust are for all practical purposes contradictory to each other. Generally speaking, data providers use obfuscation as a defensive mechanism for protecting their privacy. However, as the level of obfuscation increases, the consumer's trust in the provider decreases. Moreover, certain types of obfuscation can even render the reported data completely useless for the consumer. Drawing a boundary between defensive action and deceptive action therefore becomes nontrivial. If it is beneficial, a provider might be willing to reduce her level of obfuscation in order to gain more trust of the consumer. In other words, providers trade the privacy in return for some benefit. Therefore, for increasing the utility of participatory sensing systems, it is essential to provide effective mechanisms that enable privacy-trust negotiations.

It is worthwhile noting that the success of most of the mechanisms mentioned in Sect. 5.3.2 depends on the existence of enough redundant participants. Without this requirement it is rather straightforward for an adversary to link the reports or the reputation transfers to corresponding participants. This stresses the need for recruiting as many participants as possible to contribute enough and useful data and for guaranteeing their privacy protection and finally an efficient data analysis based on reputation of the participants and trust scores of the contributed data. For achieving this, effective incentive mechanisms must be employed to engage a large number of participants.

5.5.3 The Need for Diverse Incentive Models

Incentive mechanisms usually rely on either the rational user model inherited from mainstream economics or they try to take inspiration from other fields such as psychology and the social sciences in general. We showed that engineers and researchers in participatory systems, utilize various types of user-models in their works. In our view, it is clear that while some scenarios necessitate the usage of a rational actor model, often this model proves to be limited and fails to provide adequate incentive to much of the 'population': those who are not well-equipped to contribute highly or those who don't respond to such incentives. Therefore, it is needed to properly explore other facets such as psychological considerations, e.g., peer imitation, feel-good factor, simple heuristics etc, that people in participatory systems (may) use.

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Chapter 6
Collective Sensing Platforms

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6.1 Introduction

Collectively organized information like citizen science applications using sensors—as a form of sensor-based crowdsourcing—enable a variety of scientific as well as industrial applications (Haklay 2013) in addition to enhancing our understanding of certain phenomena for the overall benefit of human knowledge and science. The collected data of such applications and its embedded collective intelligence (Atzmueller 2012; Leimeister 2010; Malone et al. 2010) can then be leveraged for enhancing methods in various application contexts, e.g., for recommendations, various resource optimization problems, or for obtaining insights into social interactions, e.g., Mitzlaff et al. (2011, 2013a,b) and Kibanov et al. (2014), see also Chapter "Observing Human Activity through Sensing" by Gautama et al. With the advent of ubiquitous and mobile computing, many new applications have been designed for mobile devices enabling people to record environmental data (light, noise, etc.) by making use of embedded sensors, such as a microphone, camera, accelerometer, gyroscope, and GPS receiver. Hence, methods and techniques of flexibly acquiring

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and handling this data play a central role in paving the way towards behavioral shifts within large citizen populations. In this chapter, we provide an overview on collective sensing platforms, and discuss critical issues such as big data processing and sensor cloud storage.

The remainder of this chapter is organized as follows: Section 6.2 provides an overview on aspects concerning collective sensing. After that, we summarize issues of big data processing in Sect. 6.3, and sensor cloud storage aspects in Sect. 6.4. Next, we discuss specific platforms in Sect. 6.5. Finally, Sect. 6.6 concludes the chapter with a summary and outlook on interesting future directions.

6.2 Overview

In the following, we provide a brief overview on aspects concerning collective sensing. This includes a brief review of the involved topics, as well as platforms. We will discuss these in more detail in the following sections, including the respective platforms. In addition, we discuss issues of big data processing in the context of data analytics, data processing and data management. Furthermore, we discuss important aspects of storage in the context of collective sensing.

Resch (2013) defines collective sensing as "analyzing aggregated anonymized data coming from collective networks", including systems like Flickr, Twitter, Foresquare, and the mobile phone network "collective networks". The focus is mainly subjective data created by users such as comments, impressions, or perceptions. Blaschke et al. (2011) takes a more general approach and proposes "interoperable, standardized data fusion options" to be the key feature to collective sensing while not being restrictive about the data sources. Similar to Resch, the emphasis is on the ability to create "new information [...] through a combination of individual data-threads". Personal sensing is mentioned as a part of collective sensing. Vuran et al. (2004) define collective sensing in the context of wireless sensing networks (WSN), with the main feature of gaining knowledge from collectively gathered information. The term "collective sensing" is also used in robotics with the same connotation (Bishop and Klavins 2006). Thus, all definitions of collective sensing share the same underlying principle: combining a possibly large set of data streams from different sensors in order to yield information, which is not extractable from any single data stream. The most general approach does not restrict the data types being combined.

In order to leverage the wide variety of possible data streams, data must be collected, stored, and provided to applications, which aim to extract knowledge from the collected information. To this end, middleware platforms, which centralize the process of storing, processing, and accessing the collected data, such as Xively, ThingSpeak, or Ubicon/EveryAware, have emerged. Such platforms must handle certain layers of the collective sensing process, which include to certain extents: data definition (what kind of data can be accessed or stored), data alignment (store relations between data points, e.g., time, type, etc.), data processing (aggregation and evaluation of data) and data communication (querying and notification flexibility, access rights, visualization). At the data definition layer there are different sensing paradigms to handle, e.g., remote sensing, in situ sensing, stationary sensing, mobile sensing, citizen science as mobile, people driven sensing, densely vs. sparse, high vs. low quality, subjective vs. objective, etc.

All those paradigms must be handled so that the incoming data can be stored optimally for a possibly large set of different processing algorithms, and can be flexibly accessed later. The data alignment layer is closely related to data storage. Some data alignment aspects can be handled by standardized data formats. Other aspects of data alignment must be handled by post-processing the data, which is covered by the processing layer. The processing layer itself includes data alignment, but also prepares data for access and visualization. On top of that, data mining algorithms can be applied to aggregate and evaluate data and extract knowledge, which must also be prepared for easy access. Finally, the access layer provides the interface to access the processed data by applications and individual users. It may also push data to recipients. At this level it is important to correctly handle access rights as well.

6.3 Big Data Aspects

With the emergence of large-scale data collection, e.g., provided by web-based applications, social computing, ubiquitous computing, mobile computing, and collective sensing, the storage, processing and abstraction of big data is one of the current key research topics (Cuzzocrea et al. 2011; Klein et al. 2013).

In this section, we will focus on big data processing, aggregation, and abstraction aspects. In particular, we focus on the *Lambda* architecture (Marz and Warren 2013) for handling big data, the Map/Reduce framework (Dean and Ghemawat 2008), and other challenging aspects in the context of collective sensing platforms (Barnaghi et al. 2013). In the following, we first outline some typical system properties and challenges in Big Data systems, before we briefly summarize the Lambda architecture, and the Map/Reduce framework.

6.3.1 Overview

According to the *four V* criteria (Klein et al. 2013) (i.e., velocity, volume, variety, and veracity), big data requires efficient methods to handle the rapidly incoming data with appropriate response time (velocity), the large number of data points (volume), many different heterogeneously structured data sources (variety), and data sources with different quality and provenance standards (veracity). Therefore, there are several challenges that have to be addressed, such as the handling of structured and unstructured data, metric vs. qualitative data, information extraction for textual data, as well as integration techniques for the comprehensive set of data sources. For semi-structured data, e.g., rule-based methods (Atzmueller et al. 2008; Kluegl et al. 2009) and expectation-driven approaches can often be successfully applied (e.g., (Atzmueller and Lemmerich 2012; Klügl et al. 2012)). Possible extensions include techniques for handling unstructured data, and according learning methods.

Modeling large and heterogeneous data in a data-warehouse (Witten et al. 1999) requires according modeling and indexing techniques. These can be implemented, e.g., using the Map/Reduce framework (Dean and Ghemawat 2008) summarized below.

Before starting with a data processing framework, different questions and requirements need to be clarified, e.g., according to the types, structure and accuracy of data that is to be implemented, which can often be supported using exploratory approaches, e.g., Atzmueller (2015). For subjective data, e.g., adequate validation and introspection methods, e.g., Atzmueller et al. (2005, 2009), and Atzmueller and Puppe (2008) often need to be applied in order to ensure a sufficient data quality in the further big data processing pipeline. Then, also data alignment, aggregation, and analysis requirements need to be defined.

Furthermore, in addition to data processing frameworks, big data as obtained by collective sensing solutions can be turned into *smart data* by the integration of semantic information, cf., Barnaghi et al. (2013). This can also help in determining aspects of data quality, validity and trust, e.g., considering provenance information of the data, see also Chapter "Privacy, Trust and Incentives in Participatory Sensing" in this part of the book, for a discussion on socioeconomic issues. Considering the *four V* criteria discussed above, especially the velocity aspect also requires support for continuous semantic annotation, in order to ensure valid and high quality data.

6.3.2 Lambda Architecture

According to Marz and Warren (2013), system properties of a Big data system typically exhibit the following system properties: They should provide a *general* data framework that is *extensible*, enables *ad-hoc queries* with *minimal maintenance*, and *debugging capabilities*. For data storage, this implies mechanisms for handling the *complexity* of data, e.g., for preventing corruption issues and maintenance issues. Further, *robustness and fault-tolerance* should be enforced, as well as *low latency reads and updates*. This also points to *scalability* issues concerning horizontal and vertical scalability, and the option of obtaining *intermediate results* and views, according to some concept of reproducibility.

The lambda architecture incorporates these system principles and especially tackles the concept of reproducibility of results and views for dynamic processing. Essentially, it allows to compute arbitrary functions on arbitrary datasets in real-time (Marz and Warren 2013). The lambda architecture is structured into several layers briefly summarized in the following:

- Batch layer: continuously (re-)computes batch views using the immutable master data records.
- Serving layer: indexes query view, performs updates, and provides access to the dataset. Only batch updates and random reads are supported, no (distributed) writes.
- Speed layer: high-latency updates; fix batch layer lag; needs fast algorithms for incremental updates.
- Complexity isolation: random writes only need to be supported in speed layer. Results are then merged with the precomputed data from the batch layer.

In the next section, we briefly summarize the Map/Reduce framework, that can be utilized for implementing, e.g., the batch layer.

6.3.3 Map/Reduce

Map/Reduce (Dean and Ghemawat 2008) is a paradigm for scalable distributed processing of big data. Its core ideas are based on the functional programming primitives *map* and *reduce*. Whereas *map* iterates on a certain input sequence of key-value pairs, the *reduce* function collects and processes all values for a certain key. The Map/Reduce paradigm is applicable for a certain computation task, if this task can be divided into *independent* computational tasks, such that there is no required communication between these. Then, large tasks can be split up into subtasks according to a typical divide-and-conquer strategy.

Map/Reduce is a powerful paradigm for processing big data—with a prominent implementation given by the *Hadoop* framework[1] supported by the HDFS filesystem, and big data databases such as Hive[2] and HBase.[3] Map/Reduce tasks can also be utilized for batch processing in the Lambda architecture discussed above, such that continuous views are (re-)computed by the respective Map/Reduce jobs. These batch tasks can then be complemented by tools for distributed realtime computation like the Storm framework,[4] or the Flink[5] platform. This allows a comprehensive data processing pipeline for big data in the Lambda architecture, combining realtime together with Map/Reduce techniques. Alternatives to Map/Reduce, especially

[1] http://hadoop.apache.org/.

[2] http://hive.apache.org/.

[3] http://hbase.apache.org/.

[4] http://storm.apache.org/.

[5] http://flink.apache.org/.

considering *in-memory computation* with large datasets include, for example, the Spark[6] (Zaharia et al. 2010) and Flink platforms.

6.4 Sensor Cloud Storage Aspects

As outlined above, collective sensing usually goes along with a huge amount of collected data that need to be organized and stored in an efficient way. The data are usually of different data types, which increases the complexity, i.e., they exhibit a large *variety* as described above. Also, there are many areas that require continuous information in order to ensure high quality services and/or products, e.g., areas like healthcare, manufacturing, or environmental monitoring. Wireless sensor networks (WSN) provide this continuous information. They consist of distributed nodes that gather data for a given purpose, creating a huge amount of data that has to be stored and processed. However, they suffer from different disadvantages that are subject of recent research: limited memory, energy, and computation capabilities to name just a few of them (Alamri et al. 2013; Ponmagal and Raja 2011).

Cloud computing offers virtually unlimited storage, processing power, no energy issues, and more. Therefore, a combination of both, WSN and cloud computing, addresses the previously mentioned issues (Foster et al. 2009; Yuriyama and Kushida 2010). In this context, relational databases are not capable to handle the data efficiently in the cloud. Therefore, NoSQL databases have emerged, utilizing a hashed key-value storage. NoSQL is able to deal with very large semi-structured data—with the following challenges (Han et al. 2011a,b):

- **High performance:** The data must be quickly accessible, independent of the amount of stored data. Reading and writing must happen in real-time, especially in high concurrency scenarios.
- **Huge storage:** The most basic need is to store all data. This includes large partitions on the one hand and a great extent of distribution on the other hand.
- **High scalability:** The infrastructure has to be able to increase with a growing number of collected data and participants. On the other hand, it should be able to reduce the required infrastructure when the share is decreasing.
- **High availability:** Data should be accessible from everywhere. This enables flexible monitoring and analysis of the data collected so far.
- **Complex queries:** In order to enable complex data analysis, an advanced query language has to be provided. It has to handle multiple tables with lots of data across multiple distributed platforms.
- **Resource optimization:** Freeing sensor nodes from some of their tasks like storing and processing of data, reduces their complexity. This can lead to cheaper

[6]http://spark.apache.org/.

sensor nodes, a reduction in power consumption, and a maximization of the networks' life time.

- **Lower management and operational costs:** Proprietary devices are often not able to communicate between different vendors. Collecting all data in a central repository with a standardized protocol can overcome this.

Zheng et al. (2010) propose a cloud storage platform for pervasive computing environments. The authors address the limitations of single sensor nodes, as mentioned before, and present an architecture to solve them, mainly focusing on proprietary daily live sensors like smartphones or media players. However, their approach is too narrow to support wider ranges of sensor values like environmental monitoring data. In contrast, a modern sensor cloud storage should support literally every kind of data and provide as flexible access to it as possible. An exemplary generic and highly extensible data model for sensor cloud storage has been implemented, for example, in the context of the EveryAware project described below.

Another important dimension of sensor data storage and access concerns the issue of *privacy*. While this issue is very relevant, it is nevertheless not very prominent throughout the majority of the available frameworks and platforms. A notable exception is the Ubicon software platform which is discussed in the next section. It provides flexible privacy settings for data access, implementing according to guidelines for the socio-technical design of ubiquitous computing systems, cf., Atzmueller et al. (2014) and Baraki et al. (2014).

6.5 Collective Sensing Platforms

There are a number of frameworks and toolkits supporting collective sensing on different levels regarding the layers discussed in Sect. 6.2. In this section, we cover several such platforms. We compare their capabilities and highlight differences. In particular, we focus on the Ubicon (Atzmueller et al. 2012, 2014) software platform for ubiquitous social computing, and the conceptual data model devised for the EveryAware backend built on top of Ubicon (Atzmueller et al. 2014; Becker et al. 2013). Both are available under an open source license.[7]

In the following, we start with a description of Ubicon, and provide and overview on its system architecture. After that, we discuss the conceptual data model used in EveryAware, as an example of a generic and highly extensible data model for sensor data. Finally, we summarize several related platforms and discuss them in context.

[7] https://bitbucket.org/ubicon/ubicon.

6.5.1 *Ubicon*

The Ubicon software platform (Atzmueller et al. 2012, 2014) aims at enhancing ubiquitous and social networking, as a platform for flexibly implementing applications in that context. It aims at supporting applications at the intersection of ubiquitous and social computing, integrating functionalities of both environments, providing efficient and effective for building applications in areas like ubiquitous and social computing, internet of things, participatory sensing, and social crowd sourcing.

Ubicon provides a number of components for data collection, processing, and serving. At its core, it provides the means for creating and hosting customized applications. Grounded by fundamental principles of big data storage, processing, and analytics (Marz and Warren 2013), Ubicon features flexible ways for adaptions and extensions in the respective applications. Below, we first present the general system architecture, before we describe the specialized conceptual data model implemented for the EveryAware backend. This model provides for easy implementation of collective sensing modules, as exemplified by the EveryAware applications described in the next chapter.

6.5.1.1 System Architecture

Figure 6.1 shows a conceptual overview of the system's architecture. From a data-centric view, Ubicon implements a data storage, processing, and serving

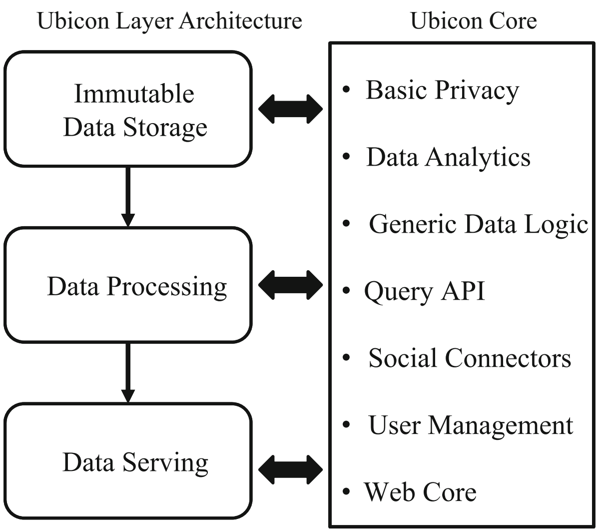

Fig. 6.1 Conceptual overview on the architecture of the Ubicon software platform (Atzmueller et al. 2014)

pipeline similar to the *lambda architecture* (Marz and Warren 2013) for handling and managing big data. In that way, core concepts such as immutability and recomputation are transparently enabled by the platform. Accordingly, the data flow is organized in the layers *immutable data storage*, *data processing*, and *data serving* providing flexible and transparent access to the data, e.g., for implementing big data analytics using Map/Reduce (Dean and Ghemawat 2008). The functionality for each of these layers is backed by the Ubicon core which provides canned functionality, i.e., framework classes and interfaces, which can be utilized throughout different applications. For more details on the architecture, see Atzmueller et al. (2014).

Overall, Ubicon enables the observation of physical and social activities. Typically, applications utilize the provided core components, interfaces, and classes and extend the overall workflow according to their individual application requirements, as also described in the chapter "Applications for Environmental Sensing in EveryAware" by Atzmueller et al. in this part of the book, for the applications of the EveryAware web application backend built on top of Ubicon. Other applications include, for example, the Conferator (Atzmueller et al. 2011), a social conference guidance system, and MyGroup, an application for enhancing social interaction in working groups. Both use active SocioPattern[8] RFID tags, which allow to localize participants and to collect their face-to-face contacts. This allows for highly personalized profiles in the systems, which can be applied, e.g., for community mining and for generating recommendations or notifications. The tags allow the coupling of real world (offline) data, i.e., face-to-face contacts, with the online social world, e.g., given by online interactions within the system or in linked online social networks. Using collective sensing data obtained using the Conferator system, Atzmueller et al. (2012) analyze the interactions and dynamics of the behavior of participants at conferences; similarly, the connection between research interests, roles and academic jobs of conference attendees is further analyzed in Macek et al. (2012). Connecting collective sensing data to online data, Scholz et al. (2013) analyzed the predictability of links in face-to-face contact networks and additional factors also including online networks.

There are several related frameworks and platforms, e.g., concerning context-awareness. The Context Toolkit (Dey et al. 2001; Salber et al. 1999), for example, provides a conceptual framework for the rapid development of context-aware applications. Similarly, Bannach et al. (2008, 2010) and Kunze and Bannach (2012) present the context recognition network toolkit/toolchain for building context-aware pervasive applications.

Compared to these toolkits, Ubicon focuses at supporting applications that consider *both* ubiquitous and social aspects. In addition, Ubicon is no general toolkit for rapid prototyping, but aims at providing general framework support for implementing and hosting ubiquitous and social applications in high-availability online scenarios. This is achieved by providing a layered template architecture with an efficient and effective data storage and processing chain. Then, applica-

[8]http://sociopatterns.org/.

tions implement this template using the modules provided by the Ubicon core components. In addition, applications can also make use of the same platform components, such that they are hosted on the same server for potentially sharing data and providing an integrated user experience across applications.

6.5.1.2 Conceptual Data Model Used in EveryAware

The EveryAware project facilitates the combination of sensor and subjective data, i.e., sensor measurements like noise or air quality related recordings and impressions, perceptions and social context. The platform enables users to collect and visualize environmental information and at the same time augment the collected data with arbitrary information explicitly supporting subjective context.

According to these requirements, we designed a specialized extensible data model. In the following, we first introduce the core data model which enables the combination of subjective and objective data and then give a short introduction into the EveryAware access and visibility concepts.

Core Data Model

The Ubicon framework provides several building blocks to support collective sensing that can be embedded into its generic data storage, processing, and serving pipeline as introduced above. In addition, it implements structures for user management and privacy handling. In order to support arbitrary sensor data, a specialized data model has been defined in the context of the EveryAware project. This also especially addresses the integration of subjective data, such as user perceptions or tags, which was one of the goals of the EveryAware project. Thus, the conceptual layer of EveryAware defines corresponding basic entities and features.

Core concepts are data points (with descriptions), sessions, and feeds. Data points and sessions can be extended by other data points. Each data point consists of a set of fixed description attributes in addition to the actual data. These attributes ensure the processability as well as dynamic querying of arbitrary content. The description attributes are divided into three categories:

- Meta attributes are attributes which allow to keep track of data independent information like received time, recording time, device ID, or session ID.
- Geo attributes make it possible to record the location of the sample being taken including longitude and latitude as well as accuracy and the provider of the location fix.
- Content attributes describe the content and its format. They help the system to further process the data. These attributes include the data type (e.g., air, noise) and format (e.g., JSON, XML, PNG).

Based on these attributes it is possible to define a variety of concepts for augmenting the data and provide subjective or social context. These concepts are sessions, extensions and feeds as listed below.

- *Sessions* are collections of data points limited to a fixed timespan. Sessions allow to introduce semantic entities such as "my way to work" or "a stroll in the park".
- Using *extensions*, data points as well as sessions can be extended with additional information using other data points. This makes the data representation very flexible and inherently supports the augmentation of objective data with a semantic context. One application is tagging. Sessions and data points can be tagged by extending them using tag data points referring to the respective data point or session IDs to be tagged. Tagging is not only restricted to actual text-tags but can be any kind of data including videos, sound files, or air quality measurement. Using this scheme, it is also possible to update data points as well as sessions after they have been sent without losing the original data. Since no raw data is deleted, this also allows to always access the version history of a data point.
- *Feeds* can be used for organizing data points. A data point is always part of the global feed, but can also be pushed into several other feeds. Users can contribute to existing feeds or create their own ones. While useful for organizing data points, feeds also allow to attach data points to real world entities such as major events like music festivals, places like the Eiffel Tower, or portable things like a smartphone. Feeds can be access restricted and a visibility level can be specified for each data point in a feed.

Access and Visibility

As discussed above, privacy is a major concern for users of data collection platforms. Therefore, adequate mechanisms and structures for privacy with respect to storage, processing and data serving need to be implemented. From an application perspective, this usually relates specifically to *data access* and *visibility*. Therefore, we aim at providing access and visibility concepts that give the users fine-grained control of what they want to share with others. To this end we base our model on feed-wise access and further define visibility levels within feeds allowing the user to choose if data can be accessed in detail or only aggregated with other data.

In general, feeds can be *open* or *closed* concerning read and write access, where *write access* refers to the possibility of adding new data points to a feed. Open feeds are accessible by everyone including anonymous users. Closed feeds are only accessible by a limited set of users (i.e., *members*). The access restriction allows users to create feeds and share them with friends or other interested users without making their data publicly available.

Since users may want to contribute in different ways to the data collected within feeds and corresponding statistics which might be derived from it, the EveryAware concept introduces visibility levels for each data point in a feed.

There are four visibility levels:

1. *Details* allows everyone who has access to the feed to see the raw content as well as the description attributes of the data point.
2. *Statistics* restricts the data point to be considered in user statistics derived from the data points in the feed, e.g., average values for the corresponding user.
3. *Anonymous* restricts the data point to only be considered in overall statistics derived from the data points in the feed, e.g., average values for an area or timespan. No association with the user is possible.
4. *None* allows only the owner of the data point to access the data point and its description attributes.

This scheme was introduced in order to allow users to share their data even if they are concerned about single data points or user specific statistics being shared.

6.5.2 Other Platforms

After introducing Ubicon and EveryAware in detail, we now summarize characteristics and features of several other platforms which support collective sensing. We especially focus on the different data models and querying capabilities. Note that regarding privacy, none of the systems includes access and visibility settings as proposed by the EveryAware backend. Most other systems group their collected data into feeds which can then be made accessible to other users, directly or by access key. In this regard, EveryAware provides a more flexible way of granting access to the shared data if correctly implemented. However, even EveryAware currently does not provide explicit support for post-processing or anonymizing location data.

In the remainder of this section, we first outline the Xively platform. Afterwards, we compare the other platforms with regard to corresponding similarities and differences.

6.5.2.1 Xively

On the data definition level, Xively[9] defines data points as pairs of timestamps and values. Values can be any kind of textual input. Data points are grouped into data streams, where a data stream usually represents a sensor or "channel" on a device. Data streams are defined by a name, tags, the unit of the values, and a symbol describing the unit. Tags are used for searching data streams. While unit and symbol restrict the input of the data stream on a semantic level, they are not enforced when uploading data. Data streams are then grouped together into feeds.

[9] https://xively.com/.

Feeds usually represent devices which are made of several sensors, e.g., a sensor box such as the Air Quality Egg.[10] Each feed may have one location stream. Feeds may also have several meta attributes like tags, a description, a website, or an associated e-mail address. Based on their definition of data streams Xively offers visualization capabilities for numeric streams. The definition of data streams is limited in a sense that data alignment or coupling between streams of a device can only be achieved based on timestamps, i.e., data streams are semantically independent.

Complex data types, as for example, accelerometer data consisting of a triple of values, either need to be modelled as several data streams or by defining a string representation used to set the value of the stream. The latter will break the visualization capabilities and limit the possible set of queries. Xively does not offer any advanced data processing besides calculating basic statistics of numeric data streams. On the data communication layer, Xively offers several endpoints for querying data. Query parameters include feeds, streams, and time intervals. It also defines a trigger API which enables to push messages upon certain events, like receiving a new value or when a value grows above a certain level. For device management, Xively features mechanisms to efficiently deploy and manage batches of devices including access restrictions based on API keys.

6.5.2.2 ThingSpeak

ThingSpeak[11] has the same basic structure as Xively. The vocabulary is a little different: ThingSpeak defines channels (Xively: feeds), feeds (Xively: data streams), and events (Xively: data points) as basic building blocks. We will use the Xively terminology for clarity reasons. For ThingSpeak feeds are limited to eight data streams extended by a location stream as well as a 140 characters long status stream. Each data point actually is a tuple of eight values, one for each data stream, as well as a location and a status message. This also allows to retrieve the tuple as a unit. Thus, in contrast to Xively, data streams are not independent making data alignment easier between data streams of the same feed. There is no additional meta-data like units or tags attached to data streams.

On the feed level several meta-attributes are available including a description, tags, a URL, and a video. The missing tags on the stream level complicate the search for data streams. Also, due to missing units as well as missing tags on the stream level, additional knowledge is required when comparing individual data streams. Just like in Xively data processing is limited. Querying data is based on time intervals. Additionally, numeric values can be constrained by upper and lower bounds and values can be summarized using different statistics like average, sum, or median. In addition, ThingSpeak allows to push data via Twitter or HTTP requests when a data stream reaches a certain status.

[10] http://airqualityegg.com/.

[11] https://thingspeak.com/.

6.5.2.3 Open.Sen.se

Open.Sen.se[12] is very similar to Xively in how it organizes data. Just like in ThingSpeak the vocabulary is slightly different but the semantics are the same: Open.Sen.se defines devices (Xively: feeds), feeds (Xively: data streams), and events (Xively: data points) as basic building blocks. Again we will be using Xively's terminology. Just like Xively a feed may contain several data streams where data points from the same "sensor" are collected. As in Xively the streams are independent. No explicit location stream is defined. Thus, when uploading a location (or any tuple based data type), longitude and latitude must either be posted in different streams and those streams must be aligned using the timestamp, or the location must be posted as a custom character string (the documentation only shows numeric data values as input).

The Open.Sen.se API[13] does not allow to add tags or any descriptive content to feeds or streams which makes collected data less understandable. Data points can specify a unit, but this is not enforced. The request API allows to retrieve by data feed or for each data stream separately. Simple constraints can be specified when accessing the data, like "greater than", "lesser than" or "equals".

6.5.2.4 Exosite Portals

Exosite Portals[14] is divided into two components: the One Platform[15] which is the backend used by the Portals component as backend. Portals is a web based API managing One Platform resources. Both use different vocabulary, but in general the structure consists of data ports (Xively: data streams) and data points. Data ports are grouped together by clients which are not really an equivalent of feeds in Xively since they are missing specific location streams and additional meta data. Data points can be numeric or character strings. Binary data is also supposed to be supported but this is not documented in the API.[16] Data streams are independent and no explicit location stream is defined. Thus, as in Open.Sen.se, locations (just like other tuple based data types) must be emulated.

There are two further concepts in Exosite Portals which are worth mentioning: client hierarchies and data processing. As mentioned before clients in Exosite Portals do not match feeds. Clients can contain any data port and data ports can be part of any client. Exosite Portals can build hierarchies of clients. This feature is used mainly for access restrictions. Furthermore Exosite Portals explicitly supports

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[12]http://open.sen.se, accessed on 19.02.2014.

[13]http://open.sen.se/dev/, accessed on 19.02.2014.

[14]https://exosite.com/, accessed on 19.02.2014.

[15]http://support.exosite.com/hc/en-us/articles/200397956, accessed on 19.02.2014.

[16]https://github.com/exosite/api/tree/master/rpc#identifying-resources, accessed on 19.02.2014.

data processing. When defining data ports it already allows to modify incoming data in the fly, by using functions like module, addition, etc.. Further more it allows to write custom scripts in the Lua scripting language and store results in new data ports. When querying data from Exosite Portals a single data port is accessed. Classically, time intervals constraints are supported. Additionally simple downsampling is supported. Exosite Portals also provides a powerful events and alert API enabling to push data triggered by a large variety of triggers. Custom triggers are supported.

6.5.2.5 Other

There are other platforms taking similar approaches as Xively, ThingSpeak, etc.. In the following, we provide more examples and sketch the main differences.

- SensorCloud[17] focuses on an efficient binary data protocol. The website also states efficient visualizations and custom analysis using scripting languages like Octave.
- Device Cloud[18] also allows to manage firmware updates of devices and focuses on large sensor deployments and their maintenance.
- Eye on Earth[19] takes a different approach, focusing on letting users create and share custom maps.
- OpenIoT[20,21] is not a platform itself but a project focused on providing a complete toolchain for internet of things deployments.
- Fulcum[22] and EpiCollect are more focused on forms submitted by users than on sensor data and the internet of things aspect which is a key theme in the collective sensing approach.

6.6 Conclusions

In this chapter, we have outlined several dimensions and specific aspects of collective sensing systems including an overview on definitions of collective sensing and state-of-the-art platforms. Furthermore, we discussed critical dimensions in this context, i.e., aspects of big data analytics, processing, and management, as well as sensor cloud storage. We discussed these issues in detail considering the server

[17] http://www.sensorcloud.com/.

[18] http://www.etherios.com/products/devicecloud/.

[19] http://www.eyeonearth.org/.

[20] http://openiot.eu/.

[21] https://github.com/OpenIotOrg/openiot/wiki/OpenIoT-Architecture.

[22] https://web.fulcrumapp.com.

applications, in particular the Ubicon software platform, cf., Atzmueller et al. (2012, 2014), applied in the EveryAware research project.

Overall, the presented systems mostly focus on data generated by sensors. Notable exceptions are given by Ubicon, and the applications built on top of it, respectively. For example, the EveryAware backend explicitly supports to augment data, in particular for including subjective information like user perceptions or tags, and supports it using a highly extensible data model for sensor data. Further examples are the Conferator and MyGroup applications implemented using Ubicon which allow the annotation of (abstracted) sensor data (Atzmueller et al. 2014).

These subjective and user driven aspects are very important in order to gain deeper understanding of the processes and environments generating the data. For example, an unexpected high value of temperature carries more value if a user also provides the cause of such a measurement, the respective event, and its context. Thus, the collected data can only be fully leveraged if information is collected which allows to derive the data's context and how it is to be interpreted. Future platforms should directly support collecting such meta data and explicitly include user feedback. In addition, these platforms should further try to interpret user feedback and extract joint information from the combination of subjective and objective data, also using exploratory tools and methods for getting first insights into the data, e.g., (Atzmueller et al. 2009, 2015, 2016).

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Chapter 7
Applications for Environmental Sensing in EveryAware

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7.1 Introduction

Participatory sensing allows to approach many research questions. Such areas include understanding patterns, semantics, and dynamics of social behavior (e. g., Atzmueller and Lemmerich 2013; Atzmueller et al. 2014, 2015; Becker et al. 2013; Mitzlaff et al. 2013; Sîrbu et al. 2015) and its interaction with the sensor data collected by the corresponding applications. In this chapter, we introduce two such applications developed in the EveryAware project for collecting different environmental sensor information, specifically concerning air quality and noise pollution. For details on participatory environmental sensing please refer to Chapter "Sensing the environment" by Theunis, Stevens and Botteldooren in this part of the book. In order to facilitate the connection between sensor data and subjective data,

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both applications provide functionality to collect impressions, perceptions, or user defined contents in form of tags. Corresponding results are for example detailed in this book in Part III, Chapter "Emergence of awareness and behavioral changes: the EA lesson" by Gravino et al.

In particular, in this chapter we describe the AirProbe and WideNoise Plus applications. Both are utilizing smartphone-based data collection modules providing means for explicit subjective feedback and are backed by the versatile and flexible EveryAware backend, built upon the Ubicon platform. The latter is further introduced by Atzmueller, Becker and Mueller in Chapter "Collective Sensing Platforms" in this part of the book. For recording the data, AirProbe utilizes a special sensorbox for measuring air quality (based on data such as NO_2, CO, O_3, VOC, temperature, and humidity) which then transmits its data using a smartphone, enabling mobile data collection, cf., (Elen et al. 2012). Similarly, WideNoise Plus provides the functionality for freely measuring environmental noise by using the smartphone's built-in microphone.

Both applications enable data access and inspection on the EveryAware web frontend: The smartphone gathers data and transmits it to our server where it is augmented and aggregated in order to provide comprehensive visualizations including for example noise pollution maps as mentioned in this book by Beate Weniger in Part II, Chapter "Cartographic Visualization of Noise and Aspects of Public Understanding of this Information". The applications have been used in several case studies, for providing first insights into collectively organized data collection in such objective and subjective contexts, cf., (Atzmueller et al. 2012, 2014, 2015; Becker et al. 2013; Sîrbu et al. 2015).

The remainder of this chapter is organized as follows: Sect. 7.2 describes the AirProbe application including the developed sensorbox and calibration steps. After that, Sect. 7.3 presents the WideNoise Plus application. Finally, Sect. 7.4 concludes with a summary and interesting options for future work. Contents of this chapter have been partially compiled from existing material, cf., (Becker et al. 2013; Sîrbu et al. 2015), in particular Sects. 7.2 and 7.3.

7.2 AirProbe

AirProbe is a mobile application for collectively monitoring air quality. To this end a calibrated low-cost sensor box has been developed: It displays the collected data on connected smartphones which are then used to upload the data to a central server. The data is then processed, enhanced and analyzed in order to generate feedback in form of statistics and map views displayed by a specialized frontend on the EveryAware web frontend. The following sections cover the basic components of the AirProbe stack, i.e. the sensor box, the smartphone application and the web frontend. Further details, e. g., about the data models used in the EveryAware web backend and the underlying Ubicon platform are described by Atzmueller, Becker and Mueller in Chapter "Collective Sensing Platforms" in this part of the book.

7.2.1 The EveryAware Sensor Box

Below, we first provide an overview on the EveryAware sensor box. After that, we give a technical description, before we discuss calibration steps and model learning.

7.2.1.1 Overview

The sensor box (Fig. 7.1) contains a sensor array of eight commercially available gas sensors and two meteorological sensors (temperature and humidity). The gas sensor array consists of low-cost continuous sensors of CO, NOx, O3 and VOC, which are important pollutants in the urban outdoor environments. These pollutants are either directly emitted by vehicles or other combustion processes, or formed from emitted precursors in the vehicle exhaust. The gas sensors were examined by a range of performance tests under laboratory and outdoor conditions. Laboratory test cycles with sensor exposure to known gas concentrations were performed, whereas outdoor tests included comparison tests with reference measurements made with high-end reference monitors.

7.2.1.2 Technical Description

The sensor box electronic system has been designed with the purpose of being a low-cost, open and scalable platform. It includes basic storage (micro SD card), positioning (GPS) and communication (Bluetooth) capabilities, and accommodates a sensor shield able to host all gas sensors.

Fig. 7.1 The Arduino board of the sensor box

The architecture of the SensorBox is based on Arduino—an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. The micro-controller on the board can be easily programmed to accomplish the tasks of the project. This system was chosen because of the simplicity with which it is possible to connect different component (shields) like GPS, Bluetooth or many others. Indeed, different shields are available on the market: they are ready to be connected and often there is a library to start programming. Considering that there is no need for complex data elaborations and that power consumption is an issue, Arduino is a good choice to have a prototype in short time. Furthermore, being an open-source project it is be possible, as we did, to review all the schematic and make a custom board with reduced dimension and cost, improving some parts if needed. The development of the SensorBox followed various steps: after having tested each single device with the Arduino board, a first version of the SensorBox was produced in order to test the integration of the whole system and start testing. Then, a second version was designed with improvements on cost, weight, dimensions and signal integrity. The main step achieved in the second version is the implementation of a new electronic design based on a four layers Printed Circuit Board (PCB). The sensor boards are positioned in an air-tight housing. A continuous air flow is generated by a suction fen and an air outlet hole at the opposite side of the sensor box.

The design is based on Arduino components and it is completely open, so that anyone can reproduce and modify the hardware or even using the original hardware and develop different software to be run on it.

7.2.1.3 Sensor Box Calibration

Issues identified by laboratory and field testing included sensor sensitivity to temperature and humidity, sensor drift in time and sensitivity to other gasses. Additionally, measurement ranges were observed to vary between sensor boxes, with values difficult to map directly to pollutant concentrations. Hence one needs to calibrate devices against a reference in order to control for these issues and obtain a measurement meaningful for the user. Calibration is a mandatory step when using low cost or adapted sensors (see also chapters by J.Theunis, M. Stevens and D. Botteldooren and by Ferreira, Kostakos and Schweizer in this volume). The target pollutant selected in this study was black carbon (BC), motivated by several reasons:

- BC is a relevant pollutant in urban environment by its adverse health effects EPA (2010);
- BC is correlated with the gases that are measured by the sensor box, as learnt from the outdoor tests (Table 7.1);
- the availability of portable BC measurement devices (micro-aethalometers, AethLabs, Fig. 7.2, also described in chapter by J.Theunis, M. Stevens and D. Botteldooren in this volume) which makes it possible to collect mobile BC data.

Table 7.1 Correlation between reference gas measurements at urban environment

	Reference monitors				
	CO	NO	NO_2	O_3	BC
CO	1.00	0.77	0.62	−0.55	*0.83*
NO	0.77	1.00	0.76	−0.51	*0.89*
NO_2	0.62	0.76	1.00	−0.53	*0.81*
O_3	−0.55	−0.51	−0.53	1.00	*−0.54*
BC	0.83	0.89	0.81	−0.54	*1.00*

Fig. 7.2 Microaethalometer: device used as a reference for calibration

Calibration consisted in simultaneous measurements with the sensor boxes and the reference device (field calibration), and then training a model that is able to map the values measured by our sensor array with the values recorded by the reference. We have used artificial neural networks (ANNs) (Mitchell 1997) for this regression task. The micro-aethalometers provide high quality measurements of black carbon (BC), however at a much higher cost (about 30 times more expensive than our sensor box). The field-calibration has been inspired by the works of Carotta et al. (2000), Carotta et al. (2001), Carotta et al. (2007), Tsujita et al. (2005), Kamionka et al. (2006), De Vito (2008), and De Vito et al. (2009).

Three types of data were used to train a calibration model, to account for three possible use cases. These included stationary data where all sensor boxes were collocated (in the same place), mobile measurements performed with one or two boxes at a time, and indoor data. Calibration models were trained in four different cities: Antwerp, London, Kassel and Turin. The representativity of the datasets is crucial. We increased the representativity of the data by placing the measurement equipment within the final area of deployment (city-specific), by collecting data continuously during day and nighttime (stationary data) and by collecting data over quite a long period (10 days) right before the final deployment (sensor boxes were used in the final test case 2 weeks later).

7.2.1.4 Data Preprocessing

Although initially the possibility of building one calibration model for each box was intended, this would not have scaled very well, so we explored the possibility of building one model for all sensor boxes. This has also the advantage that data from

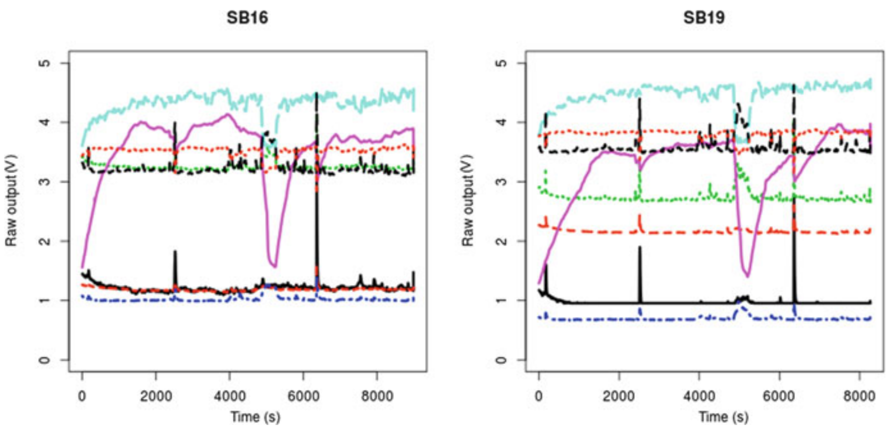

Fig. 7.3 Comparison of sensor output for two sensor boxes

multiple boxes can be used, resulting, possibly, in better modelling performance. For this, we first compared sensor output for the different sensor boxes. Gas sensors produce a signal with a value in [0, 5], however only part of this interval is actually used. It is the setting of the potentiometer (done by hand by our engineers) that determines the exact range, so differences between the output of the same sensors on different sensor boxes are impossible to avoid. However, in principle, the fluctuations should correlate. Figure 7.3 displays an example of two collocated sensor boxes and the sensor responses. While some sensors have similar ranges, some others do not (for instance the dashed red sensor). However it appears that a linear scaling could bring the values in the same interval.

Considering this, a scaling procedure was employed in order to enable the use of one model for all boxes. Using the entire stationary data when all boxes were performing measurements together, the active range of each sensor was determined and then all data rescaled so that the active range falls to interval $[0.2, 0.7]$. This allows for measurements outside the range shown during the stationary measurements to appear in the future. Any future data will be scaled using the same scaling parameters extracted from the stationary collocated data. Temperature and humidity, that also vary from one box to another (due to small differences in air flow or position) were scaled to interval $[0.1, 0.4]$. This procedure allowed us to obtain an unique model for all sensor boxes in each location, instead of individual ones for each box. Tests indicated no significant differences in model performance using sensor box specific models or a more general model that is applied to sensor box specific rescaled sensor box signals.

A different issue was data variability, both in BC values and sensor response. The BC values were post-processed by a noise reduction algorithm Hagler et al. (2011) to lower the high-frequency instrument noise that is observed when measuring at high frequency. BC levels were further smoothed by averaging over a 5 min moving window. This value was deemed suitable by comparing outputs from two aethalometers, which become highly correlated at this resolution. So the BC value obtained from the model represents an average over the last 5 min of exposure. Comparing the time series, we observed a lower sensitivity of the sensor box compared to the aethalometer, leading to delays in sensor response. To account for this, we used a smaller time window (60 s) to smooth the sensor output.

7.2.1.5 Model Training and Testing

After preprocessing, training and testing datasets were obtained for each location by combining all data types available. An ANN model for each location was obtained from the training data using backpropagation. Empirical tests showed that best performance was obtained with an ANN with one hidden layer of ten neurons, as shown in Fig. 7.4.

All training has been repeated several times and the model with best behaviour on the test data was selected. Model performance was evaluated using 3 criteria: R^2, root mean squared error (RMSE) and Pearson correlation coefficient between the modelled and the measured BC time series.

Figure 7.5 shows the result of calibration for Turin, obtained before the final test case. Two time series are shown, one in red, representing the model output, one in blue representing the data measured by the aethalometer, with evaluation criteria shown at the top, indicating very good overall results. While on training data the two time series match very well, on test data the model appears to miss some of the fluctuations seen in the BC values. This shows that, in general, the model is successful in identifying general trends in the pollution levels. However, sharp and short peaks are not handled very well by the model, and this is due to the lower sensitivity of

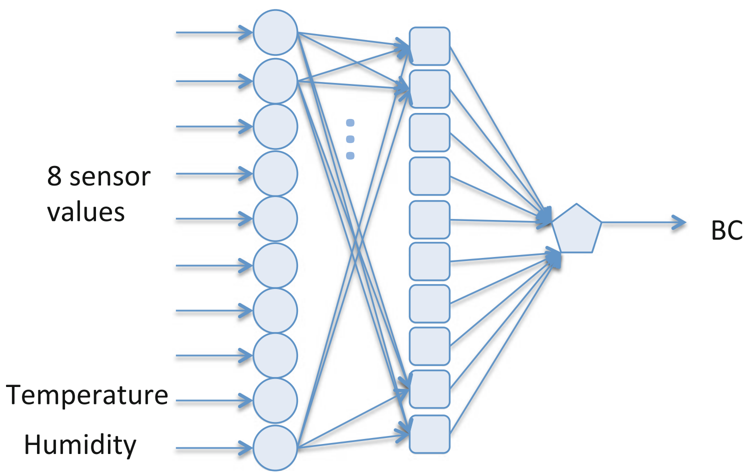

Fig. 7.4 ANN topology for our calibration problem

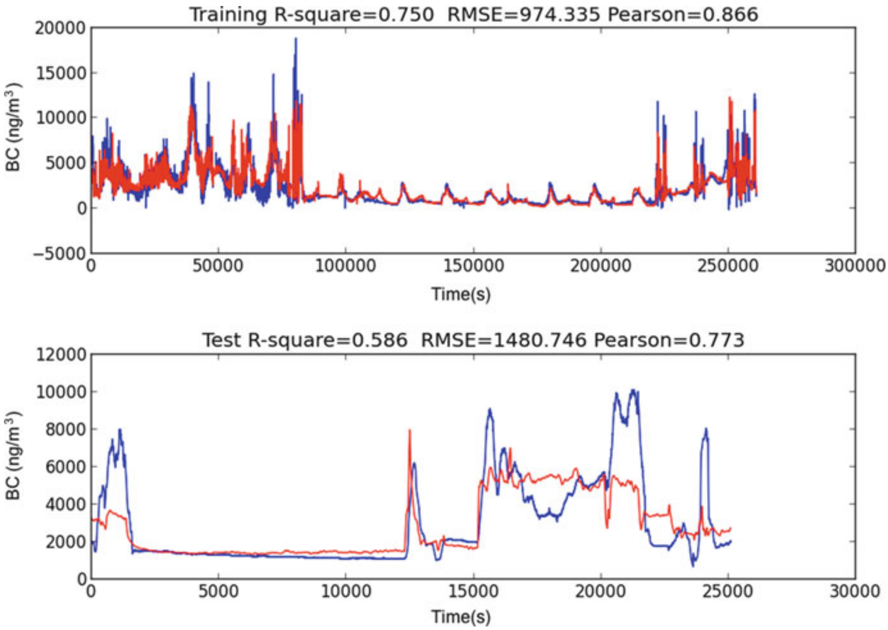

Fig. 7.5 Model performance in Turin

the low cost sensors and their delayed response. However, the performance obtained was enough for the purposes of the project, i.e. participatory mapping of pollution with multiple devices, for enhancing environmental awareness.

The ANN model was implemented both in the AirProbe application, to give the user real time feedback from the sensor box, but also server side. This approach was taken due to the fact that the sensor box has two working modes, one online and one offline. Computing model output for all offline records would have been too computationally expensive for an average smartphone, while server side this was not an issue.

7.2.2 *AirProbe Smartphone Application*

AirProbe[1] is a smartphone application for Android. It is used to read the data from the AirProbe sensor box, allows users to view, browse and annotate the data, and to upload it to the EveryAware server. Then, the data is further analyzed and processed in order to provide additional statistics and views via the EveryAware web platform.

[1]The AirProbe application is freely available for the Android platform and can be installed from Google PlayStore.

To associate the user with the uploaded data, the user first registers her account from the EveryAware backend within the AirProbe smartphone application. Afterwards there are three operational modes the AirProbe smartphone application provides: the Live Track mode, which allows to view the currently measured air quality, the Browsing mode, which allows to browse and view already collected data, and the Synchronization mode, which is used for actively managing the uploading process. In the following, we will describe these three modes in detail.

7.2.2.1 Live Track Mode

The Live Track mode allows to monitor air quality components in real time. When starting this mode, first the application will search for Bluetooth devices nearby and present the user with a list of found devices. Once the user has selected the sensor box, AirProbe starts displaying real time data collected by the sensor box, using the Bluetooth connection. The interface of the Live Track mode is composed of three different views accessible from their corresponding tabs (Fig. 7.6):

Map, where users can follow their own live track. The track is represented with different colours, depending on real-time black carbon levels. The user can also add annotations and share them on social networks (Facebook/Twitter), using the buttons at the top right corner. The track length to be shown on the map can be of 5, 15, 60 min. Live updating of the current position can be switched on and off, through the top left buttons. The bar at the top represents the black carbon value using a coloured scale (from a blue/low value to a brown/high value).

Graph, where the user can see a graph of the black carbon measurements as well as of the raw data from pollutant sensors, in a variable time interval ranging from

Fig. 7.6 AirProbe screenshots: live mode. AirProbe uses the Google Maps API to display maps (©2014 Google 2015)

1 to 30 min. The user can query the value registered by each sensor by tapping on the series. The graph is updated every 2 s.

Monitor, where users can access statistics about collected data, connection information, the status of the sensor box and the installed sensors.

7.2.2.2 Browsing Mode

The Browsing mode enables the user to access aggregated air quality measurements in the area from the server and browse their own tracks which are still on the phone. This working mode does not require an active Bluetooth connection to a sensor box. It is composed by three views, accessible from their corresponding tabs:

Map, where the user can see the black carbon levels around his current position (Fig. 7.7), by pressing the "Get nearby BC levels" button. If a track from "MyTracks" tab is selected, it is displayed on the map. The global black carbon levels and selected track can be shown together.

Graph, where the raw pollutant and black carbon evolution, calculated for a selected track, are shown. However, only tracks which have been recorded in Live Mode have black carbon data.

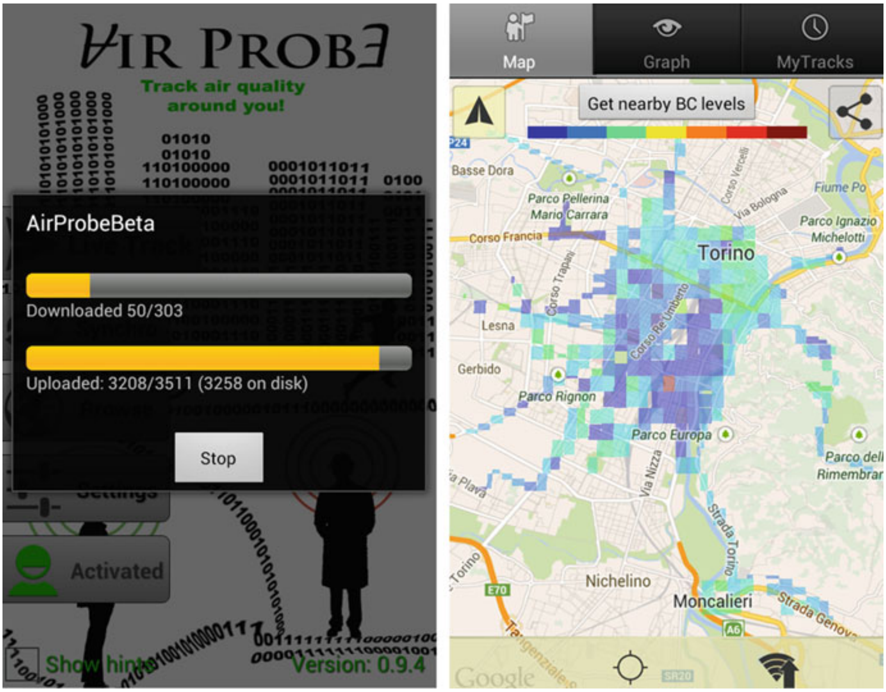

Fig. 7.7 AirProbe screenshots: synchronization and Black Carbon map. AirProbe uses the Google Maps API to display maps (©2014 Google 2015)

My Track, where the list of tracks available on the mobile device is shown. Older tracks are automatically deleted once they have been uploaded to the server and a configurable time interval since their creation has passed.

7.2.2.3 Synchronization Mode

In this working mode, AirProbe reads data from the sensor box and uploads them to the EveryAware server (Fig. 7.7). This allows the box to run without a smartphone. The user can then send the data to server in suitable conditions (e.g. where battery lifetime and/or connection billing are not a problem).

7.2.3 AirProbe Web Application

The AirProbe web application is part of the EveryAware backend (Becker et al. 2013) embedded into the Ubicon platform (Atzmueller et al. 2012, 2014) as described by Atzmueller, Becker and Mueller in Chapter "Collective Sensing Platforms" in this part of the book. It processes the data it receives from the AirProbe smartphone app, see Sect. 7.2.2, cleans it, applies Black Carbon calculation as described in Sect. 7.2.1.3, and provides several statistics and views for the user to analyze and understand her data. Furthermore, it supports case studies like the "AirProbe International Challenge" which is further described by Sîrbu et al. (2015) and in Chapter "Experimental assessment of the emergence of awareness and its influence on behavioral changes: the EveryAware lesson" by Gravino et al. in Part III of this book. In the following, we briefly introduce some statistics and views the web application provides and summarize the functionality used for the mentioned case study.

7.2.4 Statistics and Visualizations

For the AirProbe module the visualized information is represented by several views of the data including a map with different information layers as well as several global and personal statistics. The OpenStreetMap-based[2] map view visualizes the collected data on a map which allows for an easy access to the data as well as for obtaining first insights. It provides a quantitative view by aggregating samples using clusters, grids, as well as a heatmap view in order to emphasize the covered area on a global and on a personal level (see Fig. 7.8).

Further statistics calculated by the AirProbe application include summaries like latest overall measurement activity or air quality averages. Also, personal

[2] http://openstreetmap.org/

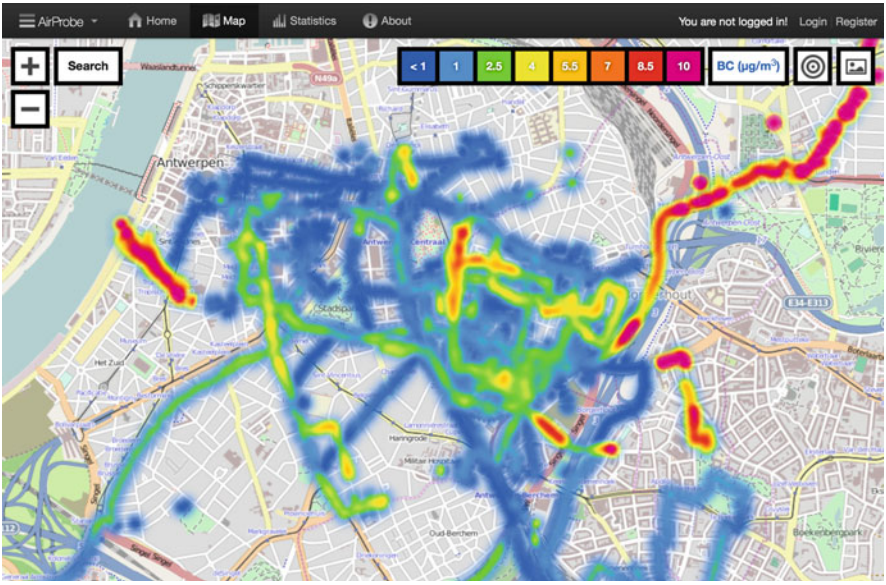

Fig. 7.8 A screenshot of a heatmap on the *map page* of AirProbe. The website map and heatmap were generated using in-house developed tools and OpenStreetMap data (©*OpenStreetMap contributors* for map data, used and redistributed under the CC-BY-SA licence 2015)

user profiles are available. Among other things, these profiles list "measurement sessions". For each session a short summary of the user's measuring activities is given. Sessions can further be viewed and explored for example by replaying the measuring process. A personal sessions overview can be seen in Fig. 7.9a. A view for exploring personal sessions can be seen in Fig. 7.9b.

7.2.5 APIC Rankings

In addition to the global and personal statistics, the web interface provides feedback for the users participating in case studies like the APIC ("AirProbe International Challenge") (Sîrbu et al. 2015). The APIC case study was held in order to gather large amounts of air quality samples and behavioral shift patterns using the sensorboxes in the four cities Antwerp, Kassel, London, and Turin.

In order to keep the motivation and competitiveness as high as possible for the teams playing, we implemented a ranking mechanism balancing repetitive sampling and coverage. The map was divided into 10 by 10 m grids. One point was given to a team when sampling within one such grid cell. When a team received a point in a particular cell, the player did not receive a point from this grid cell for half an hour. The results for each city as well as for each team have been visualized and updated in regular intervals on the AirProbe website as can be seen in Fig. 7.10. Figure 7.10a

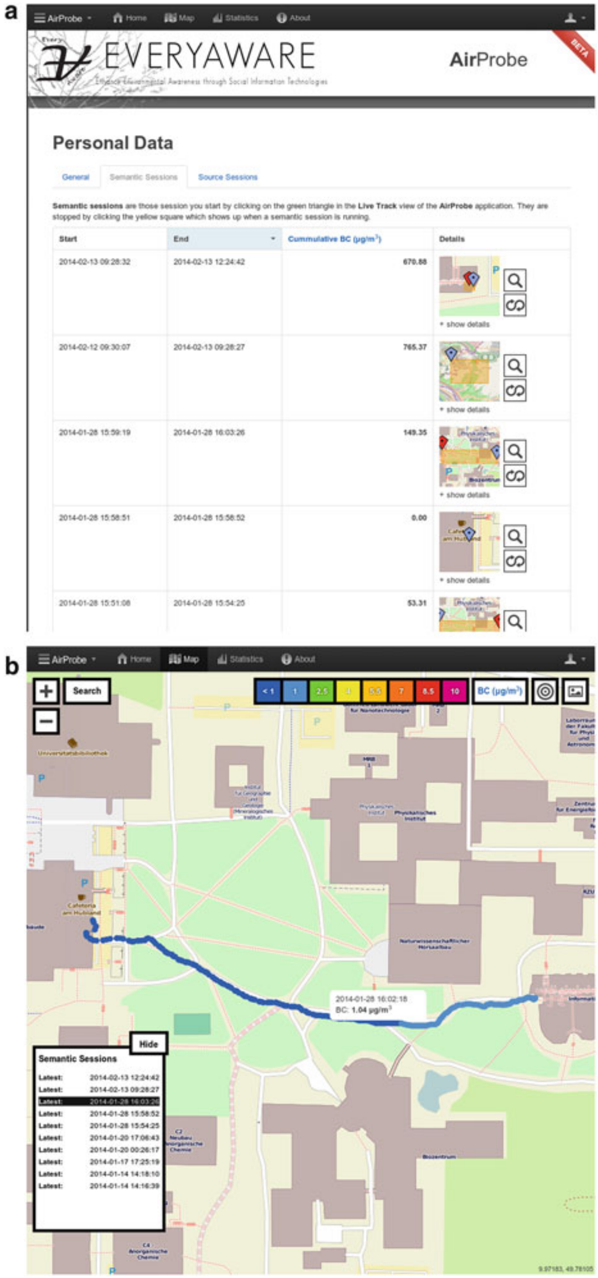

Fig. 7.9 AirProbe personal measurement sessions visualizations. The website map and track visualisation were generated using in-house developed tools and OpenStreetMap data (©*OpenStreetMap contributors* for map data, used and redistributed under the CC-BY-SA licence 2015). (**a**) This AirProbe view shows a user's personal sessions. (**b**) This AirProbe view shows a view for exploring individual user sessions

Fig. 7.10 APIC ranking visualizations. The website map and heatmaps were generated using in-house developed tools and OpenStreetMap data (©*OpenStreetMap contributors* for map data, used and redistributed under the CC-BY-SA licence 2015). (**a**) APIC city ranking. (**b**) APIC point coverage for Kassel

shows the ranking of each city visualizing the coverage and providing several statistics. Figure 7.10b shows a detailed view of the point-coverage of the city.

7.3 WideNoise Plus

There are various kinds of pollution that get often on the first page of newspapers. However, *noise* pollution is rarely cited even though it is something that constantly surrounds us even if we are not aware.

WideNoise Plus has been developed to record, monitor, and analyze such noise pollution and helps to better understand the user's soundscape. Its predecessor was developed by WideTag Inc. and was acquired and extended by the EveryAware team. Good and bad noise is not the same as loud and silent noise. One vivid examples is a rock concert. It is extremely loud on the one hand, but is mainly for pleasure on the other hand. Thus, WideNoise Plus was extended in order to support subjective annotations in order to reflect the perceived quality of the recorded noise.

WideNoise Plus is running for more than 3 years now. It is used, e.g., by the citizens around the Heathrow airport to monitor noise pollution caused by air traffic. Until now we collected more than 54,700 noise samples recorded by over 16,800 devices from all over the world. Insights into the corresponding data are reported, for example, by Becker et al. (2013), Atzmueller et al. (2015), or in this book in Part III, Chapter "Emergence of awareness and behavioral changes: the EveryAware lesson" by Gravino et al..

As a related system, Kanjo (2010) presented the first system for collecting noise data with mobile phones and discusses its implementation on a technical level. There are several existing platforms dedicated to specialized sensor data types. Maisonneuve et al. (2010) present an approach for monitoring the noise pollution by the general public using the NoiseTube[3] system. AirCasting[4] is another platform, which allows users to upload information about surrounding noise and air quality using their mobile phones. In contrast to these systems, WideNoise Plus focuses on user feedback in addition to recording noise. This feedback comes in two forms: user estimates of noise, and subjective data. User estimates help the user to gauge if they asses the noise around them correctly. At the same time subjective data is collected in the form of perceptions or tags. Perceptions range for example from a "social" feeling to solitude, or from "love" to "hate", and tags may include anything the user feels is relevant about the recorded noise. Thus, when accessing statistics the user can find patterns in how noise affects her. Overall, and in contrast to other systems, WideNoise Plus is more focused on feedback from the user, thus, allowing for a enhanced learning process with regard to awareness concerning noise pollution.

The remainder of this section is based on the article by Becker et al. (2013).

[3] http://noisetube.net/

[4] http://aircasting.org/

7.3.1 *Smartphone Application*

WideNoise Plus was developed for the two major mobile systems iOS and Android in order give access to as many people as possible. It records the noise level of the soundscape using the build-in microphone of the smartphone. No audio track is created during recording, only the loudness level every 0.5 s; therefore, the privacy of the user is ensured. The anonymous noise levels are transmitted to our application server (see Sect. 7.3.2) through a RESTful web service. Both, sensor data and subjective perceptions are required to create a full sound report, so that the application consists of two main parts:

1. Objective noise recordings.
2. Subjective annotations.

The noise recording part gives users a tool to take a noise sample through the smartphone microphone. During the recording, the user is asked to guess the current noise level using a slider where a decibel scale is mapped. The user has also the possibility of extending the default sampling time of 5–10 s or 15 s. In this way, the app will perform a longer measurement while the user gets more time to make the guess. After the recording, the noise level expressed in decibels (dB) is shown and compared to the estimation of the user. The sound level is illustrated with an icon that allows a better understanding of the measured decibel value. The icon categorize the noise level into the following groups (see Fig. 7.11a): falling feather (i.e., $[0, 30]$ dB), sleeping cat (i.e., $]30, 60]$ dB), TV show (i.e., $]60, 70]$ dB), car engine (i.e., $]70, 90]$ dB), dragster (i.e., $]90, 100]$ dB), t-rex (i.e., $]100, 115]$ dB), and rock concert (i.e., $]115, 120]$ dB). After the recording view, the users are asked to express their own subjective impression about the recorded noise. At first, they can express their opinion by moving four different sliders associated to the following concepts (see Fig. 7.11b): love/hate, calm/hectic, alone/social, and nature/man-made. At second, they can associate free text tags to the noise to further express

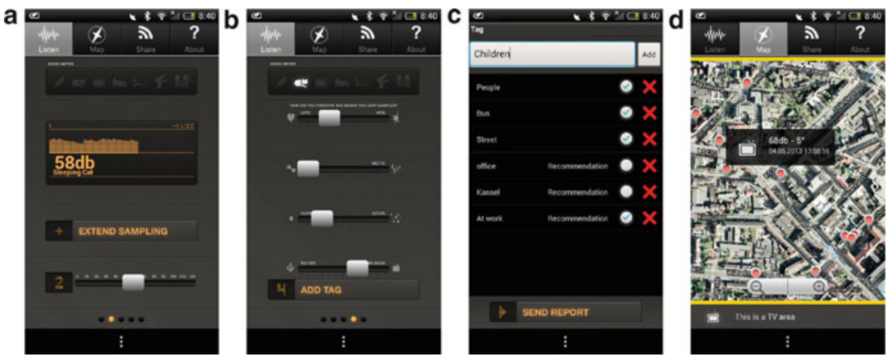

Fig. 7.11 Screenshots from the WideNoise Plus Android application. (**a**) Recording screen. (**b**) Perceptions screen. (**c**) Tagging screen. (**d**) Monitoring screen

their impression (see Fig. 7.11c). Once the subjective information is attached, all the information collected by the application is sent to the web application server as soon as a working data connection is available. WideNoise Plus allows users to view a community map displaying the average noise level at nearby locations, by relying on the statistical elaboration provided by the server (see Fig. 7.11d). As an integration with social networks, users can also share their own recordings via Twitter and Facebook.

7.3.2 Web Application

The WideNoise Plus web application (see Fig. 7.12a) is part of the EveryAware backend (Becker et al. 2013) embedded into the Ubicon platform (Atzmueller et al. 2012, 2014). It aggregates, summarizes, and illustrates noise related data collected by the smartphone application. It provides several statistics for global and personal levels and renders a map for spatial exploration (see Fig. 7.12b). Additionally, the web application provides useful information about the smartphone application and its history.

The web application provides several statistics on global and personal levels. These statistics help the user to explore and understand the data as well as to observe trends in usage patterns or noise distributions. The statistics include but are not limited to:

- The number of recordings on every day during the last 2 weeks.
- Contributing user activity distribution.
- The number of recordings during the last 3 days aggregated by continent.
- Relation between user estimates and actual decibel values.
- The three last recordings with their measured and guessed decibel value, a timestamp, the name of the location (e.g., Kassel, Germany) and the subjective annotations.
- User rankings including users with most samples, the most active users.
- The average noise level during the last day, month, and year.
- The number of registered users (those with a user account on the web server), linked devices (those registered users that linked their device to their account), and the overall number of devices.
- The average noise level per day during the last 2 weeks.
- A tag cloud for the last week, month, year, and for all collected data.

The web application also provides personalized content. Users can access their personal data and statistics via their personal page, e.g., for information on their own measuring behavior. The personal page also provides a KML export of the user's measurements as an alternative to the map visualization.

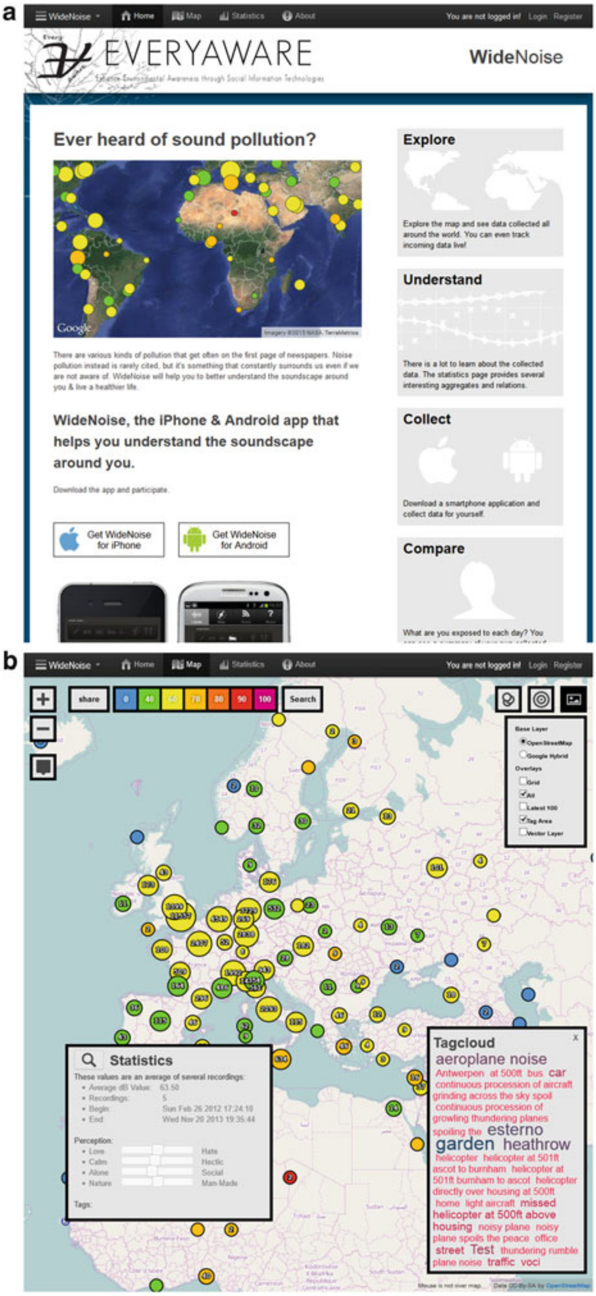

Fig. 7.12 Screenshots from the WideNoise Plus web application. (**a**) Main page. (**b**) Map page

The map page is one of the most powerful features of the web application (see Fig. 7.12b). For example, a cluster and a grid view are summarizing the noise data providing detailed information on demand. Averages of the measured noise and of the perceptions recorded by the smartphone application are available. For registered users a personalized view on the data is provided. Furthermore, a tag cloud characterizes the summarized data by its semantic context. To support social activities, the ability to forward the current view of the map to Twitter or Facebook was introduced. This allows the user to directly share and discuss interesting areas and sample distributions with friends or followers. Another feature of the map is the tracking of incoming measurements in real-time. Thus, the map connects the user to the ongoing measurement process all over the world.

7.4 Conclusions

For data collection, mobile applications (AirProbe and WideNoise) have been developed and designed to measure air quality and noise, respectively. At the same time these applications enable users to contribute subjective data. The Widenoise application uses the integrated microphone in smartphones to record noise. The AirProbe application makes use of a unique sensor box which has been designed using of-the-shelf sensors, hardware and data handling technology. Lab and outdoor experiments with the sensor box resulted in the development of a calibration model to estimate black carbon concentrations from the sensor measurements. The (mobile) measurements are then transferred to a web platform.

The design of web-based infrastructures has a great influence both on data quantity and quality, and hence also on the additional value which can be generated by analyzing the resulting datasets. Therefore, appropriate methods and techniques of acquiring and handling such data efficiently played a central role in the development of the presented applications, built on top of the Ubicon software platform (Atzmueller et al. 2014), which enables the observation of physical and social activities.

For future work, enhancing integrated exploratory techniques, e. g., Atzmueller (2015), Atzmueller et al. (2015) and extended visualization methods for geo-social data that also provide for detailed data introspection techniques, e. g., Atzmueller and Puppe (2008), Atzmueller and Lemmerich (2013) are promising options. This also concerns methods for integrated detection and analysis of anomalous and exceptional patterns, e. g., Atzmueller et al. (2009), Atzmueller et al. (2016). Furthermore, integrating advanced processing features, based on techniques for handling large structured and unstructured data, e. g., Atzmueller et al. (2008), Kluegl et al. (2009) also in the spirit of Big Data, e. g., Dean and Ghemawat (2008), Zaharia et al. (2010), seem further worthwhile directions to consider.

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Part II
Citizen Science, Participatory Sensing and Social Computation

Introduction

Mordechai (Muki) Haklay and Vito D.P. Servedio

In the first part of the book, we have explored the nature of sensing technology and how we can learn about environment conditions through their actions. In the second part we turn to the social aspects of such actions. At the outset of the EveryAware project, the awareness for participatory environmental sensing was just emerging. At the time, the head of the European Environmental Agency, gave a statement that demonstrated the realisation that only through bottom-up actions we can deal with today's challenges (McGlade 2009):

> The key to protecting and enhancing our environment is in the hands of the many, not the few. . . That means empowering citizens to engage actively in improving their own environment, using new observation techniques. . .

But how are we to achieve this? The set of chapters in Part II is providing us with some of the necessary ingredients.

The first part took a technical and engineering approach to sensing that is open to participants from all walks of life, looking at sensing devices, platforms and what technological solutions are offered to deal with issues of privacy, trust and measuring the state of the environment. In the second part, we take insights from social science approaches to participation, engagement and the use of information. We are particularly drawing on knowledge from the fields of geography, cartography, sociology, psychology, Human-Computer Interaction, and environmental studies.

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The second part of the book comprises of six chapters. The first chapter provides framing for the section, and in a way, positions the EveryAware project within the much wider study of environmental information production and use. In this chapter, 'The Three Eras of Environmental Information: The Role of the Experts and the Public', Muki Haklay makes the case that we are now entering a new era in the history of environmental information. The first era, from the 1960s to the early 1990s, focused on information that was created by experts, for experts use. In the second era, from 1990s to the early 2000s, information was also shared with the public. Now, in the third era, we see the public not only accessing information but also producing it. This analysis positions participatory sensing within the long view of public access to, and production of, environmental information.

Once the public is involved in the production of environmental information, visualisation of this information is of critical importance—both in the case of information that is provided by public authorities, where it is important to ensure that the information is legible, and in the case of public generated information, where it can serve as a motivator for further data collection. Beate Tomio (Weninger), in her chapter 'Cartographic Visualisation of Noise and Aspects of Public Understanding of this Information' demonstrates how maps play a critical role in this communication, and therefore cartographic knowledge should be used to ensure that mapping information is clear and understandable. She shows the complexities of communicating noise modelling information, including a proposal for alternative visualisation of noise information.

Another critical element of participatory sensing, especially the one that is reliant on mobile phones apps and sensing devices, is the interaction of the users with the technology. Here, knowledge from the area of Human-Computer Interaction form the basis for the chapter by Charlene Jennet, Eleonora Cognetti, Joanne Summerfield and Muki Haklay on 'Usability and Interaction Dimensions of Participatory Noise and Ecological Monitoring'. The chapter reports on empirical studies that explore how participatory sensing of noise and ecological observations is done. The two studies look at the practices of participants outside the laboratory during data collection activities. The analysis provides indication for common issues and usability challenges that need to be integrated into the design and implementation of participatory sensing projects.

Christian Nold and Louise Francis, in their 'Participatory Sensing: Recruiting Bipedal Platforms or Building Issue-Centred Projects?' take a design-led approach that questions the form of participation that is practiced in citizen science and participatory sensing projects. By positioning participatory sensing activities within the wider framework of social practices, they challenge common assumptions that underlie participatory sensing, and offer a framework that emphasises the way in which people come together around a specific issue that concerns them—an issue-centred approach to the recruitment and engagement of participants. They then show how such an approach provide effective engagement during the EveryAware project.

Continuing with examples for engagement from the EveryAware project, Vito Servedio, Saverio Caminiti, Pietro Gravino, Vittorio Loreto, Alina Sirbu and Francesca Tria 'Large Scale Engagement through Web-Gaming and Social Computation' look at how the Experimental Tribe (XTribe) platform has been used in the project to engage remote participants in social experiments and large scale human computation. The chapter explains how the system was developed and deployed, and what has been learnt and achieved through it.

The final element of the EveryAware participatory sensing—air quality—is covered by Jan Theunis, Jan Peters and Bart Elen in their 'Participatory Air Quality Monitoring in Urban Environments—Reconciling Technological Challenges and Participation'. The chapter explores the challenges and the potential of participatory sensing in the area of air quality monitoring. This chapter provides a vivid demonstration of the tensions between official and regulatory frameworks for monitoring, which have specific protocols for data collection and standards for information use, and the emerging area of low-cost sensors and DIY practices in community-led air quality monitoring. They are demonstrating that in an area that is complex on the technical and scientific level, an integrated approach in which scientists and the public work together may be the most appropriate.

The final chapter 'Getting Out of Their Way: Do-It-Yourselfers, Sensing, and Self-Reliance', by Cindy Regalado, returns to the themes that were explored by Nold and Francis, and examines the social practices that participatory sensing creates in the context of using existing tools, as well as Do-It-Yourself science. Regalado positions DIY sensing within social theory and shows how it can be framed through a conceptual framework that looks at personal aspects as well as systematic and societal aspects. She uses the bottom-up participatory sensing of the Public Laboratory of Open Technology and Science as an example for her framework, and how it relates to specific actions of bottom-up sensing.

Together, the seven chapters of Part II provide new insights into participatory sensing and citizen science that EveryAware explored. Participatory sensing is happening at the nexus of social, technical and scientific complexities. While at first sight, the two environmental elements that the project focused on have been part and parcel of public concerns about the environment for over 50 years, with evidence that air quality regulations date back to the Roman times, they are far from simple operationality. Understanding what is noise and how to measure it requires an understanding of the physics of sound production, consideration of atmospheric condition, understanding of the psychophysiological response by humans and the social, political and economic trade-offs within which the specific phenomena happens. Noise that is emerging from a noisy party in the house next door is different from traffic or airport noise due to the social-cultural context, although in terms of air vibration they might have things in common. The same physical sound at 1pm might not be considered as noise, while at 1am it will. The same is true for air quality, where what is measured, the impact on human health, the source and the potential of acting on the basis of the information form a complex web of relationships between people, technology and knowledge.

These complexities should be seen as an important ingredient in the way EveryAware evolved—they allowed the exploration of interdisciplinary understanding between engineering, physical science and social science over the way people perceive, measure, and understand the environment around them. The range of the chapters in this section provides a vivid demonstration to the way engagement and participation is understood in different domains, as well as the different facets of making it works. Together, they show the range of skills and fields of knowledge that are needed for an effective participatory sensing which yield scientifically relevant outcomes.

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Chapter 8
The Three Eras of Environmental Information: The Roles of Experts and the Public

Mordechai (Muki) Haklay

8.1 Introduction[1]

Access to environmental information and its use for environmental decision making are central pillars of environmental democracy. This statement, at first sight, seems natural—almost obvious—to anyone familiar with environmental management and environmental policy. After all, from the US National Environmental Policy Act (NEPA), enacted in 1969 and recognised since as ushering in the modern era of environmental legislation (Buck 1991), through the declarations of international environmental conferences (from the Stockholm United Nations Conference on the Human Environment in 1972 to Rio+20 in 2012) to a whole host of regulations, reports and academic discussions, environmental information is always described as central to decision making.

Yet, despite its significance, little attention is paid to the way information is created, consumed and used within environmental decision making. While attention to the technical aspects of environmental information creation or distribution are common, as are the procedural and legal aspects of access to environmental information, they are explored in a disjointed way. As a result, there is a lack of

[1]The content of this chapter is an update of material that previously appeared in Haklay, M., 2003, Public Access to Environmental Information: Past, Present and Future, *Computers, Environment and Urban Systems*, 27, 163–180; Haklay, M., 2009, The Contradictions of Access to Environmental Information and Public Participation in decision making, Nordic Environmental Social Science 2009, London, 10–12 June.

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analysis of how environmental information comes into being and by whom, who uses it and to what ends, and what is its direct contribution to decision making processes. Such an analysis is especially important in the context of participatory sensing and active public engagement in the creation of environmental information through citizen science as it allows us to understand the wider policy context in which these activities take place.

In this chapter, the history of environmental information production and use is divided into three eras, based on the identification of who creates the information and who is expected to use it. The first era starts with the emergence of the modern environmental movement at the very end of the 1960s, marked by the introduction of NEPA, and continues to the Earth Summit in Rio 1992 (the United Nations Conference on Environment and Development—UNCED). In this era, environmental information is produced by experts and scientists and is intended to be used by other experts and scientists. The second era runs from the Earth Summit and ends with the Eye on Earth Summit in Abu Dhabi in 2011. This period is marked by the opening up of environmental information to the public while maintaining the paradigm of information production by experts and scientists, as in the first era. The third era, which we are now experiencing, is marked by opening up the information production process, too. Both the production and consumption of environmental information is undertaken by the public, experts and scientists.

In fact, the transitions between each of the eras were evolutionary and not revolutionary. Yet, the different markers (NEPA in 1969, UNCED 1992 and Eye on Earth in 2011) indicate a policy level recognition of a wider change, which usually started well before the specific date of the legislation or declaration. Thus, the experiments in environmental impact assessments—which are the core of NEPA—started in the early 1960s (Felleman 2013). Despite the temporal gap between early experimentation or professional adoption and the date of the legislation or declarations, it is valuable to identify the point when the practice received official recognition, as this indicates widespread acceptance as the new modus operandi within environmental management and decision making.

As we explore each of the eras, we will look at the legal and regulatory aspects as well as examples of specific environmental information systems that demonstrate the practices at the time. Following the descriptions of the three eras, we explore the reasons for the changes, which are both technological and societal trends, as well as the implication of the new era that is currently emerging. First, we turn to a more detailed description of each of the eras.

8.2 1969–1992: Environmental Information by Experts, for Experts

In most accounts, the publication of Rachel Carson's 1962 book *Silent Spring* (Carson 1962) is considered a turning point for the twentieth century environmental movement and the emergence of 'the environment' as a substantial topic on the public agenda (Lowenthal 1990; McCormick 1995). Environmental awareness was not invented in the 1960s and what we, today, might call environmental politics predates this era (Lowenthal 1990). Yet, the connection between regulatory measures and the collection of information is linked to the early responses to the modern environmental movement. As noted, one of these responses is the USA's NEPA from 1969, which explicitly binds environmental politics and information. The two main implementation vehicles established in it are an annual report on the state of the environment and an environmental impact assessment (EIA); both are information tools. NEPA also makes the connection between environmental information and how it is distributed. When discussing EIA, NEPA states:

> All agencies of the federal government shall ...
>
> (G) make available to States, counties, municipalities, institutions, and individuals, advice and **information useful in restoring, maintaining, and enhancing the quality of the environment**; (US Congress 1970, Sec. 102, emphasis added)

NEPA goes on to connect information utilisation in the 'job specification' for members of the Council for Environmental Quality (CEQ), requiring that:

> ...Each member shall be a person who, as a result of his training, experience, and attainments, is **exceptionally well qualified to analyse and interpret environmental trends and information of all kinds**... (US Congress 1970, Sec. 201, emphasis added)

In short, though it sets out to deal with national policy to 'encourage productive and enjoyable harmony between man and his environment' (US Congress 1970), NEPA implements it through the production and use of information.

The United States was not the sole active scene of political change. Other countries went through similar shifts in policy and public awareness during this period. For example, in the UK the creation of the Royal Commission on Environmental Pollution (1969) and the Department of the Environment (1970) were the governmental response to public pressure (McCormick 1995). It is now commonly accepted that this period marks an awakening of environmental awareness throughout the developed world that was termed 'environmental revolution' (McCormick 1995; Hajer 1995), evident in the organisation of the United Nations conference on 'The Human Environment' in Stockholm in June 1972. In the action plan of the conference, information and information sharing are mentioned over 60 times (UN 1972). The major outcome from the conference was the creation of the United Nation's Environmental Programme (UNEP). From its inauguration, UNEP saw the collection of data and information about the environment as its most urgent task (Wallen 1997), based on the 'Earthwatch' principles—the evaluation and review of existing knowledge; creation of new knowledge through research; information gathering through monitoring activities and information exchange (UN 1972, Sec. C). Once the programme started, considerable gaps in data and knowledge were found. The task to fill them was handed to the Global Environment Monitoring System (GEMS) unit. By the end of the 1970s, GEMS had created INFOTERRA (the International Environmental Information System)—probably the first of its kind (Wallen 1997). INFOTERRA was operated through national focal points and provided the service of locating sources of environmental information through computerised queries (UNEP 1979). It is important to remember that INFOTERRA was running on mainframe computers, and each query was expensive to run. In addition, UNEP printed the directory of information from INFOTERRA and distributed it to national focal points.

Other notable activities on the international level happened in Europe. In 1973, the European Community (EC) moved, for the first time, beyond strictly economic issues to establish the EC environmental programme (Briggs 1986)—a medium-term plan with declared targets and goals. Though the first programme did not target informational issues directly, by the second action plan (1977) environmental information took centre stage, alongside EIA. Some of the directives and regulations that stem from those policies relate directly to data collection and information. For example, in 1979 the EC established a programme for the exchange of information on atmospheric pollution, focusing on data collection methods and improved comprehensiveness and compatibility of such data (Briggs 1986).

Within the first era, another noteworthy development that exemplifies the use of environmental information came again from UNEP. The initiative was termed the Global Resource Information Database (GRID) and was conceived around 1981–1983, with a mission to co-ordinate, within a common geographical reference system, the numerous data sets that GEMS, UNEP and other specialised agencies already had. At the heart of GRID are the concepts and technologies of Geographic Information Systems (GIS). This is how UNEP described GRID:

> . . . Existing technology now makes possible the development within GEMS of the global resource data base (GRID), which will be a data management service within the UN system designed **to convert environmental data into information usable by decision makers** . . . The technical feasibility of GRID has been assessed by expert groups . . . (UNEP 1985, emphasis added)

And a year later:

> . . . GRID technology allows us . . . initially to describe, but eventually to understand, and ultimately to predict and manage . . . GRID is also providing practical introduction to GIS technology for application in the national level . . . data transmission rates were very low, and for cost-effective telecommunication between GRID nodes, direct satellite links will clearly have to be established . . . UNEP looks forward to the day when GRID data and technology will be routinely and easily available to the entire world community to help sharpen the process of environmental assessment and guide the forces of environmental management (UNEP 1986)

To summarise, in the first era the political response to the growing public concern about environmental issues was to set in place regulations, systems and activities that were created by experts or link experts from different countries. The assumption is that only the experts can create environmental information that is suitable for decision making. In addition, because the information required specific expertise in interpreting it, an implicit assumption is that only experts will be interested in using it, so only they need access to it.

8.3 1992–2011: Environmental Information by Experts, for Experts and the Public

Experts, however, were not the only ones with interest in environmental information, and this was recognised even in the early days. As noted, the legislation for the policy instrument that opened the first era—EIA—required the disclosure of the final document to the public. Awareness to the need for public participation in decision making at the end of the 1960s is also evident in the now famous Ladder of Participation (Arnstein 1969) (Fig. 8.1), created by Sherry R. Arnstein, and addressing general urban planning processes. Arnstein identified three grouping of processes and actions that can be taken in a participation process. For her, manipulating public opinon through public relations or providing opportunity to complain but without any intention of action cannot be considered as public participation. Next, only information the public about what is going to happen or providing a short consultation are only tokenism of participation. Only when the public is involved fully in decision making a process can be called participatory.

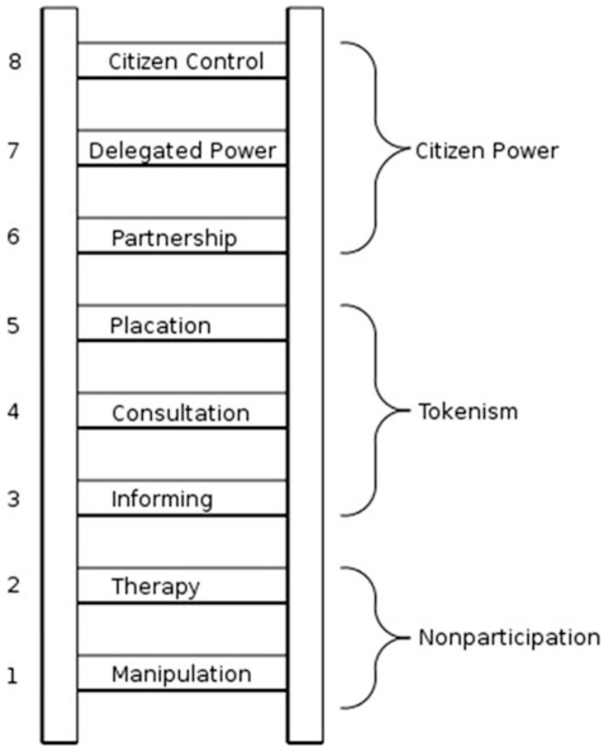

Fig. 8.1 The ladder of citizen participation (Arnstein 1969)

Notice that, in Arnstein's conception, 'informing the public' is fairly down the scale, identifying it as tokenism.

Yet, because of the prevailing stance by decision makers and experts that a decision should be based on scientific understanding which is only available to experts, the role of the public was seen as limited. This view was challenged by many, especially with the growth of environmental Non-Governmental Organisations (NGOs) such as Friends of the Earth or Greenpeace, which had access to scientists and bridged the knowledge gap by interpreting environmental information for non-experts. At the same time, these organisations also mobilised their members to have a say in decision making.

The changes in participation and access to information accelerated in the late 1980s with the publication of *Our Common Future* (WCED and Brundtland 1987) and the acceptance of the Sustainable Development principles at the Rio conference in 1992. *Our Common Future* argued that Sustainable Development calls for inclusion of environmental, social, economic and political considerations in decision making, and therefore participation of stakeholders from a wide constituency is necessary (Rydin 1999). In parallel to the realisation that the public should be involved in environmental decision making, there was growing understanding that access to environmental information should be open to all. As many have noted (Rowan-Robinson et al. 1996; Haklay 2002; Princeton Economic Research Inc. 1998), the need for environmental information spans a wide range of needs—from the educational role and raising awareness to biodiversity threats, to planning ahead for a day out.

However, to enable citizens to participate fully in environmental decision making processes, access to information has been seen as a necessary element as these processes usually rely on scientific advice and information. In the process that led to the Rio conference, access to environmental information and participation in decision making were inexorably linked. This was the result of an initiative by northern European countries to promote a 'Charter of Environmental Rights and Obligations' during the Rio conference, which was supposed to include 'the right of access of individuals to environmental information, the principle of the participation of citizens in decision making affecting the environment, and the right of access to administrative and judicial proceedings' (Pallemaerts 1992, p. 259). The initiative failed, but the Rio Declaration's Principle 10 is a watered down version, which carries through the spirit of the Charter. It is one of the most significant and far-reaching elements within the declaration:

> Environmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, **each individual shall have appropriate access to information concerning the environment** that is held by public authorities, including information on hazardous materials and activities in their communities, and the **opportunity to participate in decision-making processes**. States shall **facilitate and encourage public awareness and participation by making information widely available**. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided. (United Nations Environmental Programme (UNEP) 1992, emphasis added)

Following the Rio Declaration, work continued on extending Principle 10 and setting out the necessary legal mechanisms to turn it into action. In 1995, the United Nations Economic Commission for Europe (UNECE) in their Environment for Europe Ministerial Conference in Sofia signed the 'UNECE Guidelines on Access to Environmental Information and Public Participation in Environmental Decision-Making':

> Recalling Principle 10 of the Rio Declaration on Environment and Development which states that: "Environmental issues are best handled with the participation of all concerned citizens, at the relevant level",
>
> Recognising that **in order to increase awareness of environmental problems and promote effective public participation, access to environmental information should be guaranteed**,
>
> Recognising that public participation contributes to the endeavours of public authorities to protect the environment, and bearing in mind that environmental policy and decision-making should not be restricted to the concerns of authorities,
>
> Recognising that in order to promote effective public participation the public need to be aware of the means and methods of participation in environmental decision-making processes, and in the solving of environmental problems,
>
> Recognising that **public participation can be a source of additional information and scientific and technical knowledge to the decision makers** . . . (United Nations Economic Commission for Europe (UNECE) 1995, emphasis added)

The change in the understanding of the role of the public and its need for environmental information is noteworthy. The citation shows clear signs of what is termed 'the information deficit model' (Gregory and Miller 2000), which assumes that the public is uninformed about environmental issues and lacks the ability to understand them. The deficit model was (and is) common amongst experts and decision makers, and it is therefore unsurprising that it emerges with respect to public access to environmental information. However, the text also recognises that knowledge does not only reside with experts, and that the public can contribute useful information. These two aspects illustrate the shift that occurred in this era—there was still reluctance to open up information and participation, mixed with the realisation that times have changed and that access and participation were necessary.

The process that started with Principle 10 reached its climax in 1998, when members of the UNECE signed the 'Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters'—which is known as the Aarhus Convention (UNECE 1998): one of the most influential environmental agreements in the past 20 years. Here, the preamble reads:

> Recognizing also that every person has the right to live in an environment adequate to his or her health and well-being, and the duty, both individually and in association with others, to protect and improve the environment for the benefit of present and future generations,
>
> Considering that, **to be able to assert this right and observe this duty, citizens must have access to information, be entitled to participate in decision-making and have access to justice in environmental matters**, and acknowledging in this regard that citizens may need assistance in order to exercise their rights,
>
> Recognizing that, in the field of the environment, **improved access to information and public participation in decision-making enhance the quality and the implementation of decisions, contribute to public awareness of environmental issues**, give the public the opportunity to express its concerns and enable public authorities to take due account of such

concerns . . . (United Nations Economic Commission for Europe (UNECE) 1998, emphasis added)

The Aarhus Convention was implemented through legislation such as the EU Directive 2003/4/EC on public access to environmental information, and Directive 2003/35/EC on public participation in environmental decision making, as well as in state level regulations—for example in the UK as the Environmental Information Regulations, which came into force in 2005. Activities such as the Access Initiative (http://www.accessinitiative.org/) continue the work that started with Principle 10 and examination of its implementation across the world shows that there is still a need for implementation in many countries.

While the legislative framework of the second era was important, the agreements, conventions and regulations lagged behind the practice. This is to be expected as it took 13 years from discussions on Principle 10 to its implementation. The examples that follow demonstrate both the importance of NGOs as intermediaries and the rapid innovations that resulted from the growth of the Internet and the World Wide Web.

The first example is from Friends of the Earth UK (FoE UK), which, in the mid-1990s, had an internal GIS team with outstanding technical capabilities (Pipes and Maguire 1997). At the time, information about chemical releases from factories was collected by the governmental body (the Environment Agency) but was not available to the public. A copy of the database was leaked to FoE UK, and was then used to create the campaigning website 'Factory Watch' which was launched in 1998 and allowed members of the public to enter their postcode and see which factories were in the vicinity. Moreover, it was possible to explore the pollutants that were reported and see details about their possible health implications (see Fig. 8.2).

The Factory Watch website was a pioneer in several aspects that are important for the discussion here. First, it demonstrated the ability of NGOs to understand, access and use environmental information in a way that was meaningful to the wider public. Second, it demonstrated the sophistication and skills that were available to NGOs—at the time Factory Watch was designed, there was no 'out of the box' web mapping software and, therefore, the creation of an interactive mapping website demonstrated the level of technical know-how that FoE's GIS team had. Third, Factory Watch demonstrated the power of the Web as a public information delivery medium, with the potential to release significant amounts of environmental information to a wider audience. Finally, Factory Watch need to be seen within the context of pressuring public bodies to release environmental information to the public, which at the time was discussed at the policy level.

A second example, and a later one within this era, are the websites from around 2008 that provide access to Strategic Noise Maps, which appeared across the EU following Directive 2002/49/EC (see also Beate Tomio (Weninger), Chap. 9; and Jennett et al., Chap. 10 in this volume). The directive is discussed in detail elsewhere in this book. The directive included a requirement for member states to create maps that assess the level of noise exposure for residents in major agglomerations, as well as those living next to airports, major roads and railways. By the time the directive

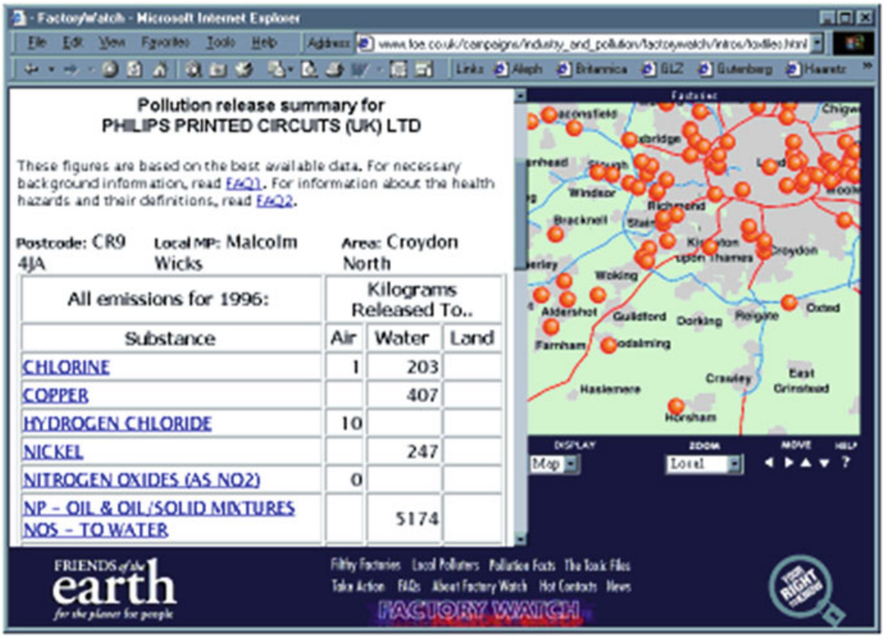

Fig. 8.2 Friends of the Earth (UK) Factory Watch website. Notice the hyperlinks for each pollutant, which provided further information, and the logo at the right-hand side: 'your right to know"

was enacted, public access to environmental information was seen as the norm, as was the use of the Web as the dissemination medium. An example of one of the first maps released to the public in the UK is provided in Fig. 8.3, for the area of London.

The Strategic Noise Maps, such as the one shown above, epitomise the second era. Experts and decision makers decided the details of the modelling process and the visualisation of information. The complex process of assembling very large data sets which included the outline of each building in urban agglomerations, developing sophisticated computerised acoustic models, the production of the results and the development of the maps was all carried out by experts with limited, if any, engagement with the public. The resulting website is littered with jargon—Lden, dB or a reference to a scenario. In addition, the map lacks some basic cartographic elements such as street names or major landmarks, which makes the output difficult to read. Moreover, the details of the modelling approach and the relationships between the maps and the noise that members of the public are exposed to in their daily lives are not explained.

To summarise, during this era several factors played an important role: regulations and legislation such as Aarhus, which mandated the release of environmental information; the rapid development of Web technology, which made it easier to build systems to deliver the information to a wider audience, coupled importantly with

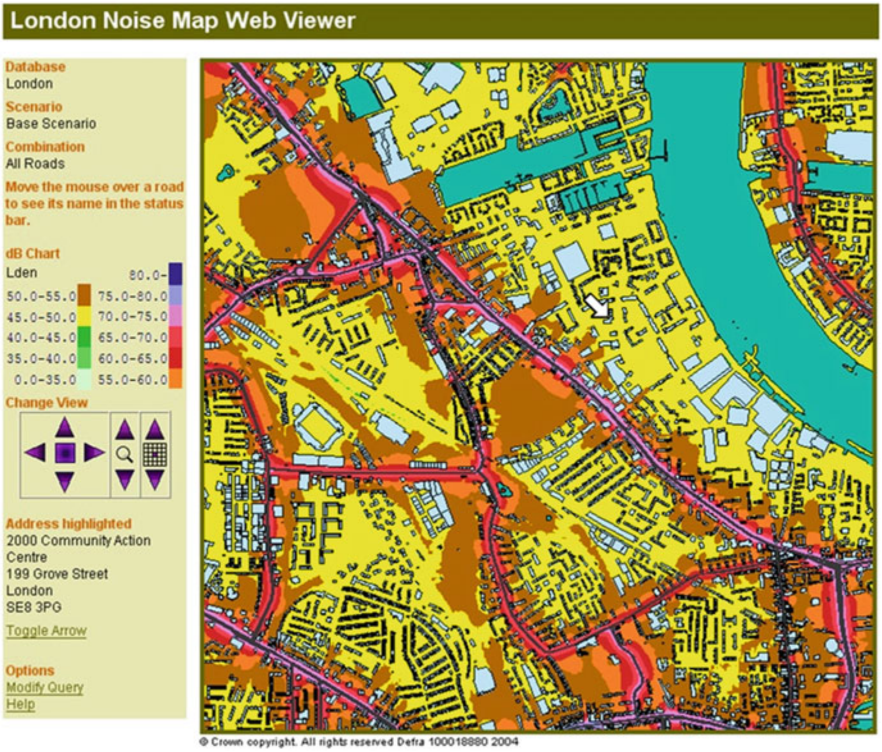

Fig. 8.3 London noise map (2008)

increased access to the Web by larger segments of the public (though a significant group, of about a quarter of the European population, remain marginalised even today); and the increased experience within public institutions and civic society organisations in using information to advance public participation in decision making. Because of these, during this era, thousands of websites emerged – some as simple as a blog with very localised information to a few that were complex, interactive and rich such as the Friends of the Earth website, or with interactive content that could be explored and customised through maps, charts and downloadable information as offered in advanced governmental sites at this time (e.g. the map of European Environment Agency Natura 2000 site, Fig. 8.4). Yet despite all the sophistication, the websites provided access to information that was created mostly by experts, and were controlled by experts.

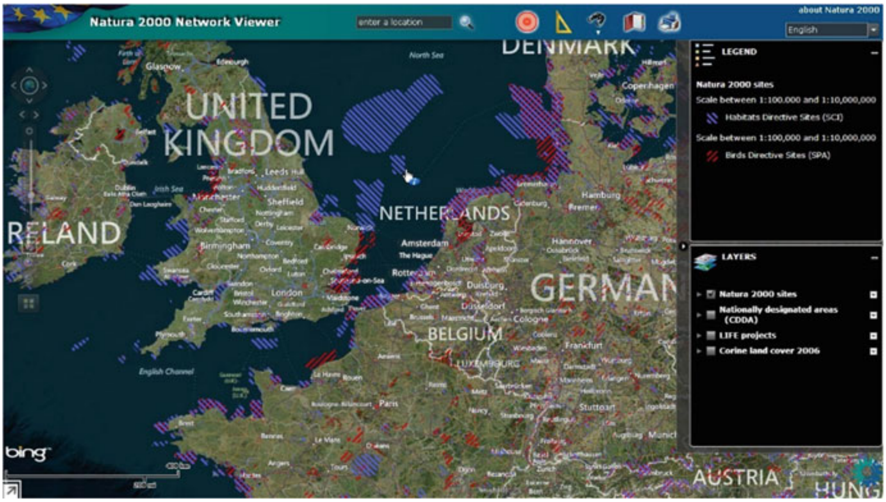

Fig. 8.4 The European Environment Agency Natura 2000 site

8.4 2011 Onwards: Environmental Information by Experts and the Public, for Experts and the Public

The last stage in the opening up of environmental information to the public is the increased acceptance of citizens, NGOs and other intermediaries as producers of information. One of the first indications of the change came in a talk given by Prof. Jacqueline McGlade, the then Executive Director of the European Environment Agency (EEA), during an international conference to mark a decade since the signing of the Aarhus Convention in 2008. In the speech, she announced the creation of a Global Citizens Observatory for Environmental Change, starting with provision of information about water quality, combined with citizens' observations (Fig. 8.5). She noted that:

> **Often the best information comes from those who are closest to it**, and it is important we harness this local knowledge if we are to tackle climate change adequately . . . people are encouraged to give their own opinion on the quality of the beach and water, to supplement the official information. (McGlade 2008, emphasis added)

Thereafter, the EEA acted as a catalyst for the increased use of environmental information provided by the public and for increasing the awareness to it among decision makers. The official acceptance of the public as producers of information and not mere consumers is slower. In the preparatory process of the Rio+20 conference (held in Rio de Janeiro in 2012) UNESCO proposed to include the following statement:

> The contributions of science, including the natural sciences, social sciences and engineering, to sustainable development are deep and multifaceted. **Communities need to collectively address common pressing challenges facing our society**, such as food

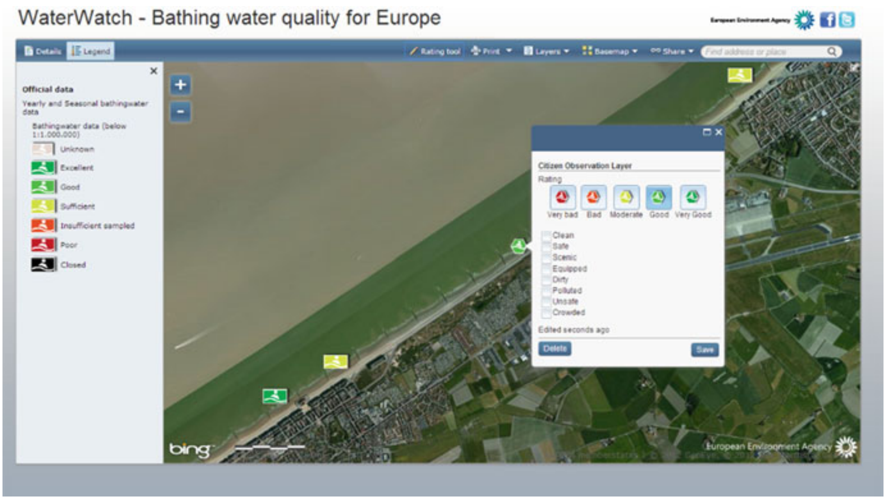

Fig. 8.5 The European Environment Agency Water Watch site, allowing citizens to provide a rating of water quality based on personal observations

> security, climate change, natural disaster risk reduction, biodiversity loss, access to clean water, management of terrestrial and marine resources, energy security, and affordable and effective health care. In addition, science and technology and innovation (STI) serve as a major engine for social and economic growth, generating entirely new industries, products, and services and creating jobs for our youth. Science and engineering contribute not only to understanding our world but to acting for change to the benefit of society. To move forward it is clear that a new compact between science and society is needed, one that more effectively promotes dialogue among scientists, policy-makers and society at large (UNESCO 2011).

The rationale associated with this statement mentions environmental information that is generated by the public—known as citizen science—explicitly. In the final version of the conference declaration the suggested text from UNESCO is not included, and the move beyond Principle 10 is more nuanced:

> We underscore that **broad public participation and access to information and judicial and administrative proceedings are essential to the promotion of sustainable development. Sustainable development requires the meaningful involvement and active participation** of regional, national and subnational legislatures and judiciaries, and all major groups: women, children and youth, indigenous peoples, non-governmental organizations, local authorities, workers and trade unions, business and industry, the scientific and technological community, and farmers, as well as other stakeholders, including local communities, volunteer groups and foundations, migrants and families, as well as older persons and persons with disabilities. In this regard, we agree to work more closely with the major groups and other stakeholders, and **encourage their active participation, as appropriate, in processes that contribute to decision-making, planning and implementation of policies and programmes** for sustainable development at all levels (UN General Assembly 2012, item 43, emphasis added)

Within the process that led to the Rio+20 conference, the Eye on Earth Summit (held in Abu Dhabi in 2011) provides a clearer indication to the change in environmental information production. The summit focused on environmental information and the sharing of it and included examples of environmental information collection by the public. Examples of citizen science included educational initiatives in the US as well as indigenous knowledge sharing in the Amazon. The final declaration discussed the role of stakeholders in creating and sharing information:

> . . . the objectives of our collaboration are **to foster collaboration among communities, relevant networks, systems, institutions and technology providers on the integration of economic, environmental and social information in a shared information system for the advancement of sustainable development** by taking advantage of the rapid development of information and communication technologies and by strengthening capacity building and technology support to developing countries and countries with economies in transition (UNEP 2011)

While what the declaration means by 'communities' is open to interpretation, there is a clear extension of the canvas in recognising the roles of many actors in the creation, dissemination and use of environmental information. The statements in the declaration were strengthened two years later, during the first meeting of the Eye on Earth network in Dublin, in which the final statement explicitly states that the parties:

> Decided to continue to collaborate through the Eye on Earth Network, to promote, support and improve access to data and information for sustainable development and, where appropriate, by participating in special initiatives, collaborating on related technical developments, **establishing citizen science as an important source of knowledge within the diversity of knowledge communities**, building capacities across the network and convening meetings to achieve this goal (Eye on Earth Network 2013)

The Dublin statement needs to be recognised for what it is—the meeting was not a core environmental negotiation meeting with actionable obligations or even a strong international statement. Yet, this is the first example of official recognition of citizen science as a source of environmental information. It is left to be seen how citizen science will become recognised within international and national legislation, and we can expect the process to follow the activities that occur on the ground, to which we now turn.

There is, of course, irony in the fact that it took nearly half a century to open environmental information creation to the public, due to two aspects. First, as noted, it was the public's pressure that started the modern environmental movement, and this was based on growing public awareness of environmental problems through books and the media that provided environmental information. Second, and more importantly, many of the data sources that were used by scientists to provide input in environmental decision making were created by citizen scientists. Biological observations and meteorological records are the results of the efforts of many volunteers—in some cases this was a sustained effort over many decades and even centuries (Dickinson and Bonney 2012). Moreover, the funding for the organisation that maintained and coordinated the data collection activities came from the demand for the data for environmental decision making. However, the source of the data was marginalised or even ignored and, until recently, only the analysis of the data and its scrutiny by experts gave it authority and respectability.

In addition to these long-standing citizen science activities, a new form of environmental citizen science emerged at the end of the 1990s and the beginning of the 2000s. An example of this is the Global Community Monitor, an organisation that, since 1998, has developed a method to allow communities to monitor air quality near polluting factories (Scott and Barnett 2009). The sampling is done by members of the affected community using widely available plastic buckets and bags followed by analysis in an air quality laboratory. Finally, the community is provided with guidance on how to understand the results. This activity is termed 'Bucket Brigade' and is used across the world in environmental justice campaigns.

Another example of the new capabilities that are provided to citizens to contribute environmental information in novel ways is provided by the range of applications that are available on smartphones. The applications allow participants to use the sensors in their phones to collect and share observations about the environment. This can be sensing vibrations or noise level, as well as annotating and contextualising the observations. Many of these applications are described and explored in other chapters of this book (see Part I).

8.4.1 Drivers of Change and Implications

As we have seen, over the past 50 years a remarkable transformation in relation to environmental information has happened: from the stance of not only should production of environmental information be done by experts, but they should also be responsible for interpreting it reliably, to the acceptance that both the process of production and use of environmental information is open to the public. Throughout the period, experts continued to have the main role within environmental decision making processes—from advising the US President in the CEQ to summarising the latest science for the Intergovernmental Panel on Climate Change (IPCC)—but the relationship between the experts and the public has changed. To understand this change and to explain the three eras, we briefly look at the societal, political and technical changes that enabled them. What follows is an attempt to pinpoint the main factors that explain this transition.

The societal transition, which includes the rise of a more networked society identified by Castells (1996–1998) and others, is central to the shift. Of particular importance is that the increasing level of education and access to higher education, rising to almost half of the 17–30 cohort in the UK in 2012, has been an ongoing trend since the 1960s when only 5 % participated (Wyness 2010). Therefore, while in the first era the general public needed the experts to make sense of scientific information, the situation changed rapidly to a situation where many members of the public had the skills to do so themselves. In addition, the growth of interest in environmental issues, and especially the exponential growth in the amount and ease of access to environmental knowledge in the form of academic articles, governmental reports and educational material, allowed more people than ever before to understand the underlying scientific issues that are the basis of environmental decision making, and therefore the demand to participate in them increased.

On the political side, especially in environmental decision making and the discourse of environmental democracy, there was a growth in acceptance that decision making cannot be made in a top-down manner alone. The declarations about the importance of allowing democratic interventions in environmental decision making led to the opening up of the process. The environmental area is one of the first that officially accepted the role of civil society organisations to act as representatives of interests—some of them of non-human (e.g. organisations that focus on the protection of birds or wildlife). Because environmental decision making is so reliant on environmental information, this political transition meant that access to information was a necessary prerequisite of effective participation. Later on, the recognition that indigenous and traditional knowledge should be taken into account when a decision is made meant that the door was opened to public creation of environmental information.

Finally, both enabling and enabled by the social and political changes, technology not only transformed the availability of environmental information, but also the amount of information and the ability to process it. A good example are geographical information systems (GIS), which are core to the collection, organisation, analysis and visualisation of environmental information. The beginning of the first era coincided with the establishment of one of the earliest GIS companies—the Environmental Systems Research Institute (now known as Esri)—while, by the beginning of the third era, the ability to deliver detailed maps to a mobile device became ubiquitous in many parts of the world. Many other digital technologies—from the ability to network and deliver data, to satellite technology and to the World Wide Web—are critical trends that explain the evolution of public access and public creation of environmental information.

Finally, we consider the implication of the last era we are entering into. The opening up of environmental information in both creation and application, and the advent of expectations that access to information will be provided free of charge, changes the nature of environmental decision making. Without falling into utopian traps, it is clear that the ability of members of the public to create their own environmental data sets or to analyse existing data sets means that we will see different arguments emerging about environmental issues. Because the public can carry out citizen science activities as well as analysing existing and newly created data sets, official data sets will come under scrutiny and be compared to locally produced information. The role of the expert will also be challenged—the expert will not be able to claim that, because they are ‘exceptionally well-qualified in analysing environmental trends and information’, they have the last word. We can expect calls for more nuanced analysis, explanations that discuss uncertainties and complexities, and even technical discussions about analysis methodologies that explore the limits of expertise. At the same time, there will be plenty of roles for the experts as those who can provide synthesis and interpretations, as they are still likely to be the only members of the public with the luxury of dedicating all their time to the topic in question.

In a way, the journey from 1969 to today can be seen as an increasing democratisation of environmental decision making, in the sense of increasing equal participation within decision making processes. While inequalities within society in terms of education, access to technology or participation in democratic process cannot be ignored, and there is a significant distance to go for fuller democratic participation, we can now see how environmental information acted in its own way as a democratic catalyst.

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Chapter 9
Cartographic Visualisation of Noise and Aspects of Public Understanding of this Information

Beate Tomio (Weninger)

9.1 Introduction

Maps are *the* major instrument for the assessment of noise in European cities. They are the basis for informing the public *and* for formulating action plans. Environmental noise that is the subject of this chapter is defined as “unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity” (European Parliament and Council 2002, Art. 2(1)).

In 2002 the European Parliament and Council adopted the Environmental Noise Directive 2002/49/EC (also known as END). As the “main instruments to identify noise pollution levels” it aims to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise” (European Commission (EC) 2014). To monitor noise, EU member states are called

- to *draw up strategic noise maps* for major roads, railways, airports and agglomerations every five years, starting in 2007;
- to inform and to consult “the public about noise exposure, its effects, and the measures considered to address noise in line with the principles of the *Aarhus Convention*[1]”;

[1]The *Aarhus Convention*, adopted in 1998 by the *United Nations Economic Commission for Europe* (UNECE), gives everyone the right to access environmental information that is held by public

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- to draw up action plans to reduce noise—limit values and measures are not predefined, but are at the discretion of the competent authority;
- to develop "a long-term EU strategy" to reduce the number of people affected by noise (European Commission (EC) 2014).

These actions are of high importance as noise is "amongst the most relevant environment and health problems, just behind the impact of air quality" (European Commission (EC) 2014). Around 40 % of the EU population are exposed to road traffic noise at levels exceeding 55 dB; 20 % are exposed to levels exceeding 65 dB during the daytime; and more than every third citizen is exposed to levels exceeding 55 dB at night (World Health Organization (WHO) 2013). Exposure to these noise levels does not only lead to high levels of annoyance, but also to known health effects. The dose-effect relationship between noise level and annoyance was outlined by Schultz as early as 1978 (Schultz 1978). In 1999 the *World Health Organization* (World Health Organization (WHO) 1999) specified that an equivalent continuous sound pressure level of 50 dB causes moderate and a level over 55 dB considerable annoyance at an exposure of at least 16 h. The risk for high blood pressure and cardiac infarction increases with a long-term average exposure over 55 dB. As a consequence the OECD established daytime thresholds for annoyance at 55–60 dB, measured in LAeq[2] and states that over 65 dB "human behaviour patterns are constrained and symptoms of serious health damage arise" (Stevens 2012, p. 92).

Due to the high health risk the presentation of noise in maps is of high importance for the assessment of noise pollution and to serve as a discussion basis as well as to inform the public. Therefore the directive stipulates "that the strategic noise maps [. . .] and the action plans [. . .] are made available and disseminated to the public in accordance with relevant Community legislation[3] [. . .], and in conformity with Annexes IV [minimum requirements for strategic noise mapping] and V [minimum requirements for action plans] to this Directive, including by means of available information technologies". As to the information of the public it is defined that it "shall be clear, comprehensible and accessible" (European Parliament and Council 2002, Art. 9). This statement complements international declarations, such as the *Rio Declaration on Environment and Development* in which principle 10 states that "each individual shall have *appropriate access to information* concerning the environment" (United Nations Environmental Programme (UNEP) 1992, emphasis added) (see M. Haklay, this volume).

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authorities, the right to participate in environmental decision-making, and the right to review procedures to challenge public decisions (http://ec.europa.eu/environment/aarhus/).

[2] L_{Aeq} or L_{eq} is the equivalent continuous A-weighted sound pressure level (cf. Sect. 9.2.3) that is, for example, the main indicator for aircraft noise in the UK. It describes the daily average movements during the 16-h day (7–23 o'clock local time) calculated over the 92-day summer period (16 June–15 September).

[3] Relevant community legislation is for example Directive 2003/4/EC that repeals Directive 90/313/EEC that was addressed in the END.

Although the access to environmental and noise information is highlighted as a principle, declarations and directives do *not* give any further indication as to how this aim is being met. The aim's fulfilment therefore is a matter of interpretation. How would appropriate information be defined? This depends on how the concept of accessibility is being defined, in a technical sense as giving access to a document or in a broader sense as giving access to the information *in* the document. To inform the public effectively it is insufficient to merely disseminate information. It is important to make sure that the aim of delivering specific facts is being met. Enabling access to information therefore should not only be understood in a technical sense, but rather in a user-oriented way, both task-oriented and context-dependent. Information is only useful to citizens if underlying data is up-to-date, accurate, and processed as well as visualised in a way that is suitable for the target group and context and hence beneficial to them. Users should be able to achieve their goals after performing a task, such as getting an overview of noise levels in an area, or learning about the change of noise levels, by means of the disseminated information. Giving people access to environmental information in a way that they are able to make sense of it is a prerequisite to empower them by gaining knowledge.

Since noise maps are a crucial factor in giving access to noise information, they are the subject of discussion in this chapter. The author aims to elaborate on aspects of visualisation that are relevant for public understanding and the interpretation of noise maps. The focus is on selected aspects of map design and its suitability for the purpose of informing about environmental noise. Moreover, the author focuses on the benefits that an integration of crowdsourced noise information would have on noise maps. Thus, first of all, noise as a physical measurement as well as its psychophysical and physical characteristics are described and summed up to show how this phenomenon is presented in noise maps. Of special interest is the visual representation of the characteristics of noise. Secondly, the current state of noise presentation in END-conform maps is discussed with special focus on the colour scheme and the noise contour lines. An alternative colour scheme is suggested that follows the characteristics of the presented noise indicator. Noise contours for aircraft noise are compared to contours for traffic noise to discuss if these contours are suitable to represent different noise sources. Thirdly, the author delivers insights into the cartographic challenges of crowdsourced noise mapping and how such data can be beneficial to END-conform mapping, e.g. to integrate qualitative information. Cartographic analysis and lessons learned from interviews and discussions with experts and users in Germany and the UK form the basis for the explanations that follow.

9.2 Noise: A Challenge for Visualisation

9.2.1 What Is Noise?

Noise is "(a) sound, especially when it is not wanted, unpleasant or loud" (Cambridge Dictionary, in (Stevens 2012, p. 82), "especially one [. . .] that causes disturbance" (The Oxford Dictionary, ibid.). However, the definition as unwanted and unpleasant is very vague as people react differently to noise in different situations and different times of the day. Annoyance caused by noise nuisance "shall mean the degree of community noise annoyance as determined by means of field surveys" (European Parliament and Council 2002, Art. 3c) and is context-dependent: "27% of people are 'highly annoyed' at 55 dB (L_{den}) due to aircraft noise, whereas only 6% of people are 'highly annoyed' by road noise of the same level" (European Environmental Agency 2010 cited in Airports Commission 2013b, p. 11).

In terms of physics there is no difference between noise and sound; therefore "noise" is a psychosocial term and highly subjective. Even though noise is perceived subjectively, certain sound levels cause ‚objectively observable harm" (Stevens 2012, p. 88). Therefore, regulations like the END that aim at building an objective basis for the assessment of environmental noise are important. Environmental noise is defined as "unwanted or harmful outdoor sound created by human activities, including noise emitted by means of transport, road traffic, rail traffic, air traffic, and from sites of industrial activity" (European Parliament and Council 2002, Art. 3a). This vague definition that does not define any thresholds, but that is based on a classification of disturbance and annoyance already provides insights into how challenging the communication of noise situations can be. Additionally, psychoacoustic principles that are discussed in the next section also contribute to this challenge.

9.2.2 Psychoacoustic and Physical Principles of Noise

Psychoacoustics puts the physical, objectively describable sound that hits the ear in relation to the subjective perception (Gunther 2011). With the help of psychoacoustics, sound perception can be described in a user-centred way that puts priority on an individual's perception instead of the physical measurement. This is especially important as perception and physical measurement vary widely.

Sound pressure is the local pressure deviation from the ambient atmospheric pressure caused by a sound wave. Loudness depends on sound pressure; but the first is the subjective perception, the latter is the objective physical measure. The connection between sound pressure level and loudness is complex because loudness is also dependent on frequency, which is perceived as pitch. Individual sensitivity varies for different frequencies as Fletcher and Munson (1933) proofed. Their studies resulted in the initiation of equal loudness contours that are now part of ISO 226:2003 (ISO 2003). To incorporate this non-linear connection into the measurement of noise, the so-called A-weighting was introduced internationally, i.e. sound pressure levels are reduced or increased according to perceived loudness, which is indicated with “(A)” next to the unit dB. A-levelling is not something that is well-known by laypeople, however, it does not really have any implications for the understanding of a value or visualisation. Because perceived loudness is frequency-dependent and is already considered in the presented values.

However, the fact that the measure sound pressure level is logarithmic does have consequences for both communication and comprehensibility. The logarithmic scale was introduced because humans can perceive sound pressure from about 20 μPa (0.00002 Pa) to 200 Pa. The visualisation of values spanning over seven orders of magnitude is not manageable. Therefore, the logarithmic measure Sound Pressure *Level* (SPL) in the unit dB, was introduced. The logarithmic scale results in some specialties: Classical arithmetic operations are not valid because SPLs have to be added up energetically.[4] Therefore, higher values contribute more to a mean value than lower ones. The mean value for an area with 60 and 80 dB is 77 dB—not as many would expect 70 dB. Whereas the doubling of sound intensity for broadband, incoherent sound sources results only in an increase of 3 dB due to characteristics of sound. In noise maps, therefore, the presented sound levels in 5-dB-classes only appear linear due to equidistant classes. In fact, higher values are more important as they contribute more to the average pollution, but people are used to arithmetic operations and compare values, implying a linear character.

The logarithmic character of the noise pressure level and the fact that the noise pressure level does not represent loudness have major implications for the comprehensibility of noise levels in noise maps. Therefore the author strongly recommends considering these specialties for the visualisation by giving additional information and adapting the graphic style, e.g. colour, to the characteristics of the presented phenomenon.

9.2.3 Requirements for the Graphic Presentation According the END

A strategic noise map is defined as a “presentation of data on one of the following aspects: an existing, a previous or a predicted noise situation in terms of a noise indicator, the exceeding of a limit value, the estimated number of dwellings, schools and hospitals in a certain area that are exposed to specific values of a noise indicator, the estimated number of people located in an area exposed to noise.” (European Parliament and Council 2002) (Annex IV, 1.) They can be submitted to the European Commission as graphical plots or as numerical data, in tables or electronic form. For

[4]This means de-logarithmised, added or averaged, and then logarithmised again.

informing the public, however, more detailed information in the form of a graphical representation is essential. This should include the exceeding of a limit value and the presentation of a noise indicator. The main indicator to be presented as the indices L_{den}[5] (day-evening-night equivalent level) and L_{night} (night equivalent level) is the Sound Pressure Level (SPL). The indices are computed or measured according to prescribed ISO standards. Existing national methods can be used if they can be adapted to the indicators set out in the END. The 5 dB range of L_{den} and L_{night} at an assessment level of 4 m above the ground for contours of 60, 65, 70 and 75 dB is the major information about noise in the maps. Separate maps have to be drawn up for road-traffic noise, rail-traffic noise, aircraft noise and industrial noise.

As common with European-wide directives, the minimum requirements for strategic noise mapping are very limited and not sufficient to attain a homogeneous presentation across countries. Further specifications can be added by national guidelines as long as they do not conflict with EU-guidelines. Some national states, for example Germany have additional guidelines that specify colours to be used or demand a higher number of presented classes.

In summary, it can be said that the requirements according the END are not sufficient to achieve comprehensibility and accessibility for the general public, because no minimum usability standards are defined. Additionally, as presented above, noise is a complex phenomenon and meeting minimum demands might not be enough to present noise as an urgent matter and thereby provide a basis for discussion as well as decision-making. For further illustration the author now discusses two aspects of noise visualisation below.

9.3 The Presentation of the Sound Pressure Level in END-Conform Noise Maps

The following sections provide an overview of the cartographic presentation of END-conform noise maps. The focus is on the colour scheme and its suitability for the representation of the sound pressure level and the presentation of noise contours as the major cartographic content. Both aspects will be described with regard to the characteristics of noise. For a comprehensive outline of the visual encoding of acoustic parameters, the colour scheme and the interpretation of noise maps see Schiewe and Weninger (2013) and Weninger et al. (2015a, b, c).

[5] L_{den} is the A-weighted (cf. Sect. 9.2.3) long-term average sound level for daytime, evening and nighttime (7 am–7 pm, 7 pm–11 pm, 11 pm–7 am, with possible offsets for certain countries). An extra 5 dB is added for the evening level and 10 dB for the night level.

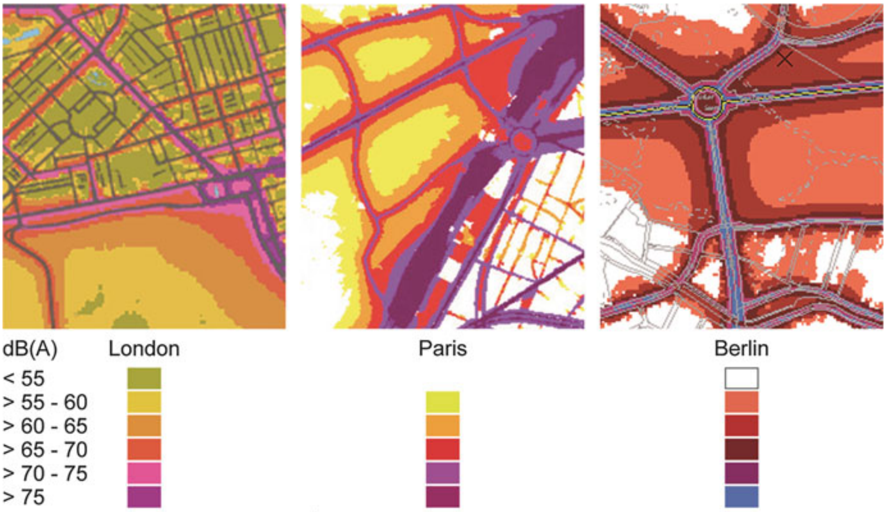

Fig. 9.1 Official noise maps of the cities of London, Paris and Berlin showing L_{den} for 2013. Saturated colours for lower values, especially *yellow* and *orange*, distract from the hotspots (Defra (Department for Environment & Food & Rural Affairs) 2014; Stadtentwicklung Berlin: 2014; Bruitparif 2014)

9.3.1 The Colour Scheme Representing the Sound Pressure Level

9.3.1.1 The Prevalent Colour Scheme

The major visual variable representing the sound pressure level is colour. It is used as an area filling for the isophones or equal-noise contours for traffic and railway noise (Fig. 9.1). Since the distribution of aircraft noise is less complex—the major noise source is the runway—only black contours instead of coloured areas are used (Fig. 9.2).

Throughout Europe similar colours are applied (Fig. 9.1). This is due to ISO standard 1996-2:1987 (ISO 1996) which suggested a colour scheme that is still in use as a reference point although the scheme was removed with the revision of the standard in 2007. In Germany this colour scheme is still part of the German Industrial Standard DIN 18005-2 (Beuth 1991) and compliant to law[6]

[6]This was the status at the editorial deadline of this volume in November 2015. The German Industrial Standard DIN 18005-2 (Beuth 1991) will be replaced by DIN 45682 that was under revision at the editorial deadline.

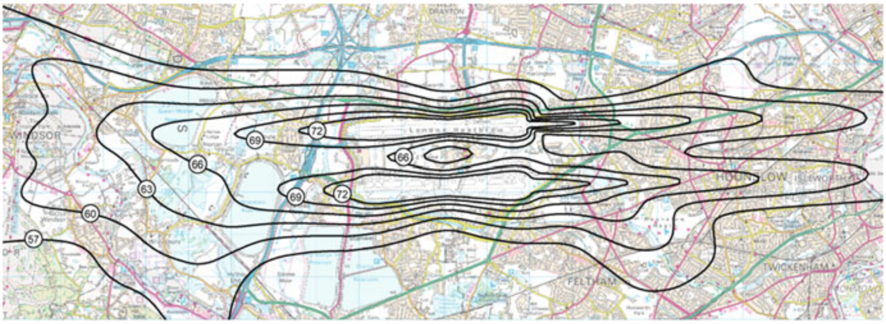

Fig. 9.2 L_{eq} noise contours in 2012 for Heathrow Airport, standard modal split (78 % W/22 % E) (Gov.uk 2012)

(34. BImSchV[7]). Noise experts generally agree on the unsuitability of the scheme. From a cartographic perspective the following weaknesses can be identified:

- The SPL's values are ordered from low to high, thus it is advisable to apply a sequential scheme with an obvious decrease of lightness, according to cartographic conventions (Brewer 1994). However, the prevalent scheme has big hue and lightness steps. Therefore the colours cannot be put in an intuitive order. This, however, would be necessary to facilitate an easy identification of the SPL's distribution patterns.
- Saturated colours—yellow and orange—are used for values in the middle of the scale. Therefore the amount of colour is unbalanced in the map, as warm saturated colours appear further in the front than cool colours, and therefore do stand out (Luebbe 2012). This effect is due to physiological reasons, and is especially bad for yellow. Values belonging to middle classes are rather overrepresented in terms of area when contrasted to very high values' areas, which increases this effect. Consequently schemes consisting of different hues should not only have a clear decrease of lightness to imply an order, but should also be balanced in terms of saturation, i.e. saturation ideally increases for the higher values.
- To consider colour conventions and connotations is cartographic practice. In noise mapping it is practice to use green and red as signal colours to indicate low and high noise levels. The first problem that arises in this context is related to the point mentioned above: Saturated red is used for values in the middle of the scale, which leads to misinterpretation as red is usually used as a warning colour and highlights levels much more than the blue shades that are used for very high levels. The second crucial issue is to address colour vision deficiencies (CVD). Around 8 % of male and 0.5 % of female users have difficulties to discriminate

[7] Vierunddreißigste Verordnung zur Durchführung des Bundes-Immissionsschutzgesetzes (Verordnung über die Lärmkartierung) vom 6. März 2006 (BGBl. I S. 516).

red from green or are not able to do so at all (Jenny and Kelso 2007). For reasons of accessibility and since this information that is intended for public use, it is unacceptable to neglect this aspect.

As the author has shown, the representation of the SPL is the major aspect of END-conform noise maps and therefore the colour design is not just an aesthetic issue, but a crucial one to allow people who use the information to understand environmental noise, highlighting hotspots and calm areas. Ideally the colours would even reflect the characteristics of noise outlined in Sect. 9.2.

9.3.1.2 Proposal for an Alternative Scheme

Based on the issues raised above, the author has developed an alternative colour scheme (Fig. 9.3) with respect to colour vision deficiencies (CVD), perceptual as well as psychological effects of colour (Weninger 2013), *and* the characteristics of noise. The scheme has been presented for acceptance in the revised version of DIN 45682 that will replace the aforementioned German Industrial Standard DIN 18005-2 (Beuth 1991). Underlying requirements for the development are as follows:

- Discriminability of colours for people with CVD as well as when used on a variety of screens;
- consistency of colours independent from adjacent and background colour to facilitate a matching of colours used in the map with colours of the map legend;
- colours have to be logically assignable to the characteristics of the noise data; i.e. presented noise levels should not be under- nor overestimated, hot spots and calm areas should be determined by the users without referring to the map legend and colours should facilitate an association with the categories of noise levels.

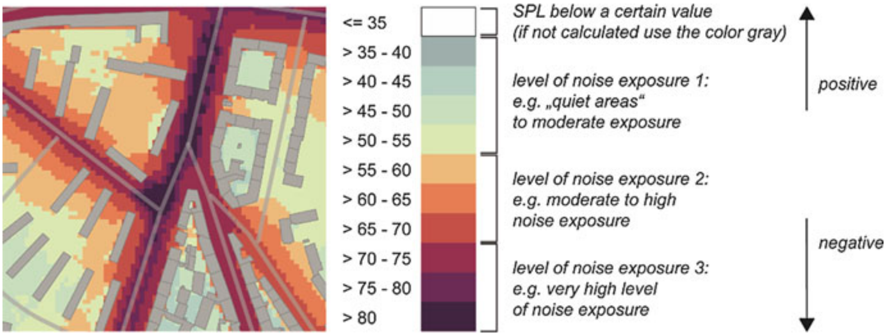

Fig. 9.3 The new colour scheme for the representation of the SPL uses the hues *blue-green*, *orange*, and *purple* with an increase of saturation. Colour codes can be found on www.coloringnoise.com (colours are optimised for digital use)

To fulfil these established requirements a scheme with the following characteristics has been developed in an iterative process comprising four user studies: (1) A harmonic hierarchy is attained by using three hues—blue-green, orange, purple—that are arranged according to lightness so as to facilitate an ordering; thereby we apply a maximum of four steps of lightness per hue, which enhances discriminability. (2) Each hue stands for a certain noise level and, therefore, supports discriminability and recognition. (3) A bipolar scheme was implied, using greenish shades for low levels, analogous to a traffic light system. It is supposed to support the contrast between calm areas and a high level of noise exposure. (4) The logarithmic character has been taken into account by applying an increase of saturation for high levels. Thereby, high values that contribute more to a mean value are highlighted. The wide range of values that comes with taking the logarithm is represented by a wide range of hues—blue-green and purple are almost complimentary colours. (5) To make the colours accessible for users with colour vision deficiencies the author has avoided the combination of pure red and green and used a blue-green and purple instead.

The colour scheme has been tested in four user studies with a total of 232 participants. The user studies aimed to test the effects of colour on the interpretation of noise exposure, to assure the discriminability of the colours as well as the association of the colours with levels of noise exposure, and to test the representation of value ranges by means of the colours of the scheme. The results of the user studies show that the new colour scheme is suitable to represent the characteristics of noise. For colour codes and more information please visit our website www.coloringnoise.com.

9.3.2 The Suitability of Noise Contours to Represent Noise Situations: An Example of Aircraft Noise

The SPL's presentation by means of noise contours is laid out in the END and is *not* subject to change. However, it is to be discussed if the presentation is suitable for the range of noise sources and if the SPL is sufficient for a comprehensive representation of noise. The first use-case is the assessment of noise. In this case the target group are experts who have background knowledge to make sense of the information and they have learned how to read the maps because of frequent use. The target group of the other use-cases of informing and consulting with the public, however, differ strongly. For this user group the maps have to be self-explanatory and the information salient because users usually have no learning phase and have to understand the maps immediately when they use them.

For the consultation of citizens, the presentation by means of contours of one single index is not sufficient to discuss the topic thoroughly. A focus group interview with people affected by the noise of London's Heathrow Airport demonstrated that people's day-to-day experience is not appropriately reflected in prevalent presentations of aircraft noise, as a participant in the focus group explained: "But the crucial [incomprehensible] I found with all of them [referring to contour maps, cf. Fig. 9.2] they just didn't match up to my experience. So that's when I lost interest in the noise contour maps [incomprehensible] and then got on to the web track site[8] which shows you delayed version of what's [. . .] going into Heathrow. And that matched much more closely to my experience [. . .]".

The focus group revealed those aspects, in which aircraft and traffic noise differ. A look at these differences helps us to understand the characteristics of noise events and to define what is of importance for the visual presentation. The first difference between traffic and aircraft noise is that airplanes are not restricted to fixed routes as cars. They follow "Noise Preferential Routes" (NPRs), but these are liable to change. While the contours for traffic noise are arranged along roads, right at the source, and are therefore comprehensible, the contours for aircraft noise are arranged around the runway like "pond ripples" as another participant observed and do not reflect the aircraft's physical presence in form of flight tracks that are perceived by the residents.

Additionally, when compared to traffic noise, aircraft noise, for e.g. Heathrow Airport, is subject to change between westerly and easterly operation of the airport. This so called "runway modal split" is an effect of year-on-year weather fluctuations that require use of runways for take-off or landing in line with prevailing wind (Civil Aviation Authority 2013). The presentation in the maps depends on the period under consideration: e.g. the last year or the last 20 years. As a result, the presentation does not necessarily reflect what residents experienced recently. The uncertainty between what is experienced and what is modelled is thus bigger than for traffic noise.

The major difference, however, is the frequency of noise events that is intermitted for aircraft noise but rather continuous for traffic noise. Aircraft noise is clearly characterized by short bursts of extreme noise events that recur in a specific rhythm. This means that maxima can be *much* higher than the average: "L_{Aeq} flattens the peaks and troughs of measured sound energy over a period of time [. . .] as if it was experienced continually" (Aviation Environment Federation (AEF) 2010, p. 6). "65_{LAeq} 16h can be made up of 45 events at 96 dB SEL[9] or 450 events at 86 dB SEL". It does give no insights into the *real* situation (Airports Commission 2013a, p. 22). Consequently, the number of noise events is a crucial characteristic. Indicators like L_{den} or L_{Aeq}, however, cannot reflect this as "a doubling of movements produces an increase of only 3 dB L_{Aeq}" (Aviation Environment Federation (AEF) 2010, p. 6), but according "the findings of the ANASE[10]

[8]An example for a web track site is https://de.flightaware.com/live/airport/EGLL.

[9]The Sound Exposure Level is the "the sound level, in dB, of a one second burst of steady noise that contains the same total sound energy as the whole event. In other words, it is the value that would be measured if the energy of the entire event were compressed into a constant sound level lasting for one second." (Airports Commission 2013a, p. 19).

[10]Department for Transport (2007) Attitudes to Noise from Aviation Sources in England (ANASE) study.

study [. . .] annoyance is strongly influenced by the number of aircraft passing overhead." (Aviation Environment Federation (AEF) 2010, p. 22).

Although the author described just a few differences between traffic and aircraft noise it becomes obvious that noise sources have special characteristics. This fact has to be considered in the visualisation to comprehensively reflect a noise situation. Noise contours seem to be less suitable for the visualisation of aircraft noise than for traffic noise.

As the form of presentation and the indicators that have to be presented are clearly specified in national and EU law the author suggests the presentation of additional information in the form of additional map layers, diagrams, or information graphics that reflect residents' experiences and specific characteristics of noise sources for a non-expert target group. Moreover, adding qualitative information, e.g. from crowdsourcing is of high value to reflect subjective experiences, to which we now turn.

9.4 Crowdsourced Noise Mapping: Cartographic Challenges and Benefits

In parallel to official noise mapping activities by EU member states, a number of projects deal with the crowdsourcing of noise data in cities (see C. Nold and L. Francis, this volume). This approach is owed to the high number of smartphones in urban areas that can be used as sensors for environmental measurements by citizens (see C. Jennett et al., this volume). Noise can be recorded and measured using the built-in microphone.

Looking at this alternative mode of noise mapping, first the author reflects on the cartographic challenges due to the data source and data format and then suggest benefits from crowdsourced data.

Projects that deal with noise mapping of crowdsourced data are, for example, *EveryAware* (EveryAware 2014), *NoiseTube* (NoiseTube 2014), and *da_sense* (da_sense 2014). They all provide apps—*WideNoise,*[11] *NoiseTube Mobile*[12] and *Noisemap*[13]—that facilitate the measurements and upload to a web map. Although the intention is to map noise in cities, the specific goals of the projects differ from the END objectives. The clear objective of the END is to "define a *common approach* intended to *avoid, prevent or reduce* on a prioritised basis the *harmful effects*, including annoyance, due to the exposure to environmental noise" (European Commission (EC) 2014), emphasize added. The projects goals, in contrast, are "monitoring noise pollution by involving the general public" (NoiseTube 2014), "environmental

[11] http://www.widetag.com/widenoise/ (accessed April 2014).

[12] http://www.noisetube.net/download (accessed April 2014).

[13] http://www.da-sense.de/ (accessed April 2014).

monitoring, awareness enhancement, behavioural change" (EveryAware 2014), and gathering and distributing high quality and quantity sensor data (da_sense 2014). Considering the aim is vital to discuss the presentation in maps, as is the data format. In the projects the emphasis is rather on the users' interaction than on informing them by means of visualisation: Users become aware of noise in urban space (see K. Akerlof, this volume), track it and hereby gain knowledge, upload it and therefore contribute to a database *and* an online presentation of noise in cities (see P. Gravino et al., this volume).

We have seen that the indices L_{den} and L_{night} are complex and difficult to comprehend, but also the smartphone measurements are not straightforward. People might feel rather in control of the measurements if they take action themselves, but in fact the assessment of the data quality is complex as well for the following reasons that are pivotal for visualisation:

The length of the recordings contributes greatly to the information quality. *WideNoise* standard recordings e.g. are just 5 s and can be extended to 10 s. A short recording is convenient for the data collectors, but it is obviously only an indication for the noise level in this short time frame. The number of recordings and therefore total time is a major indicator for data quality because the average value is based on it. On the map, however, it is not always clear how many recordings the information is based on. *WideNoise* indicates the number of measurements by numbers directly in the area representing the SPL (Fig. 9.4). *Da_sense* shows as they state "loudness", which is actually the SPL, as aggregated hexagons or tiles, the number of measurements, however, is indicated only in the interactive mode (Fig. 9.5). It is problematic if the number of recordings contributing to the represented values is not shown. Because then information based on a single recording appears to be as important as information based on many recordings at different times. In the interest of comprehensibility the number of recordings should be considered in the visualisation e.g. by using transparency of symbols or symbol size for point data. However, even if a high number of recordings is available, this does not mean that they are distributed evenly throughout the day. Additionally interactive filters could be applied that help users to explore the data to find out, for example, when the data was collected.

While authoritative data is modelled considering a number of input data and presented as equal noise contours, crowdsourced data is mostly presented as point-data and based on at least one measurement. The problem with point data is that it has to be enlarged to be visible on the map. Therefore single points appear as a circle-shaped area and partly overlap, dependent on the aggregation for different zoom levels. This gives the wrong impression that SPLs can be clearly delineated, especially if a borderline is used (Fig. 9.4). In fact, only the centre of the circle-shaped area marks the collection point. The coverage of the SPL, other than in contour maps, can actually not be derived. The same problem applies when

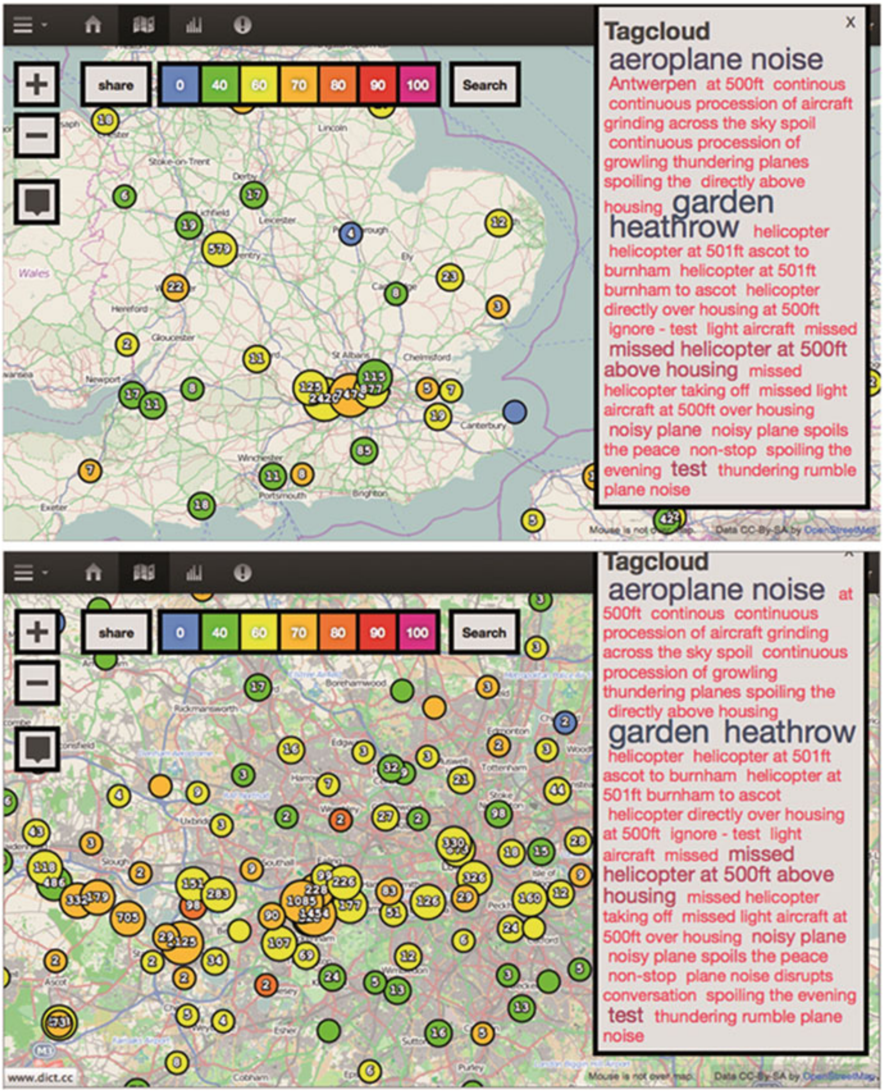

Fig. 9.4 The *WideNoise* map in two different zoom levels reveals the aggregation of the measurements and their appearance as areas. The tag cloud on the *right* shows users' subjective tags for the data points

data is aggregated to hexagons or tiles (Fig. 9.5). Measurements then seem to be area-covering, but some areas are only interpolated or extrapolated based on one measurement. This form of representation can therefore only reflect an assumption of the noise situation.

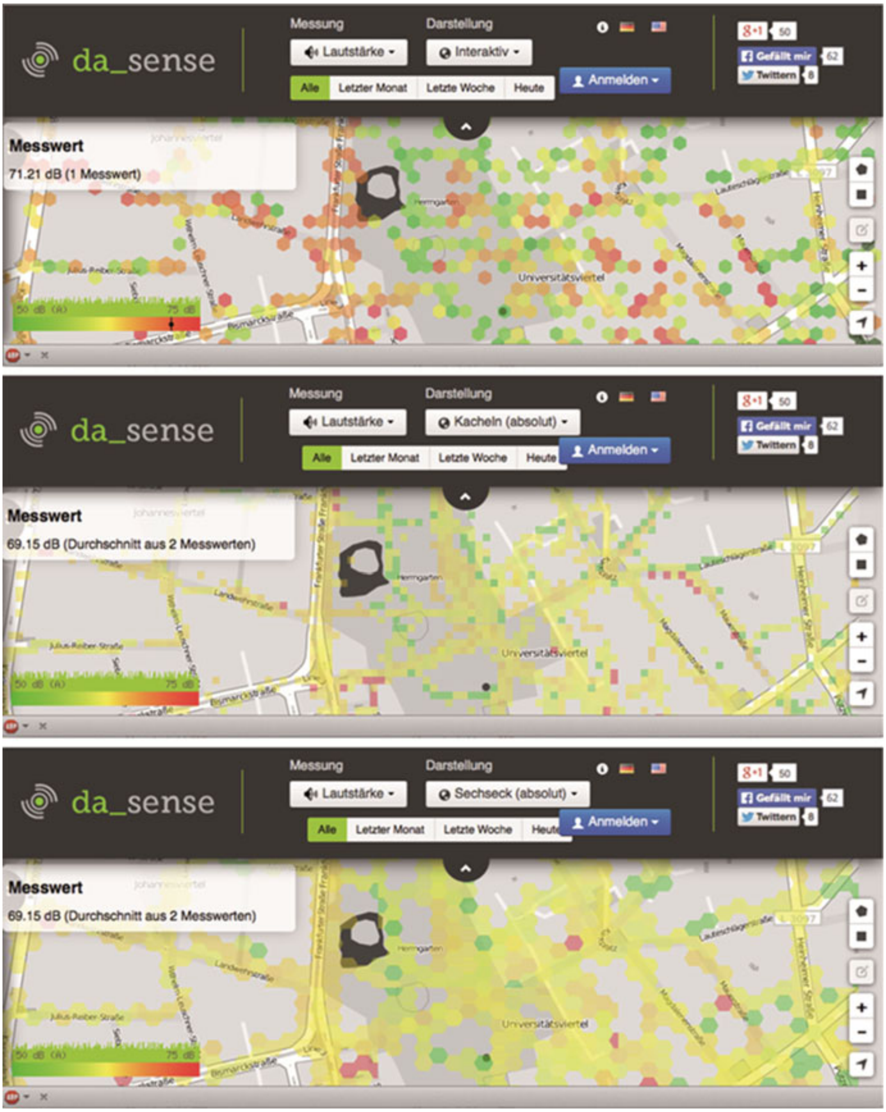

Fig. 9.5 The *da_sense* map in different modes:"loudness" shown as interactive hexagons, with the number of measurements in the box in the *upper left* corner, as tiles, and as hexagons. Although the zoom level and input data were not changed the impression of the visualised data changes obviously without an indication for the reason

A measure of data quality is uncertainty: "Uncertainty is inherent in all kinds of spatiotemporal data and is caused by uncertainty in the real world, limitation of human knowledge, limitations of measurement technologies, and the potential to generate and propagate uncertainty in processing and analysis (Shi 2010 cited in Kinkeldey 2014). Considering uncertainty in visualisation is likely to support decision-making and reliable information. In the case of noise recordings the first uncertainty to mention is geometric uncertainty that is caused by positioning errors. Own experiences show that, although a recording was done at the same location several times, measurements were not aggregated and visualised in the map as one point, but as different ones, which affects average values.

The major uncertainty that we are facing in crowdsourced noise mapping, however, is the uncertainty of the measurement itself (see J. Theunis et al., this volume). This is caused by hard- and software differences (NoiseTube 2014). The apps *Noisemap* and *NoiseTube* therefore provide calibration profiles for a range of smartphones.

Additionally, there is thematic and temporal uncertainty: People tend to put their focus on the recording of obvious noise events. It is not self-evident to record silence in the course of noise mapping. This again effects average values. Also, the noise source of the recording cannot be controlled. Although, for example, the *WideNoise* app was especially advertised to people affected by aircraft noise and data collection activities were arranged with this specific target group, the actual noise sources of the recordings are unknown and do not necessarily need to be environmental noise. In agglomerations it is most likely that the recording is a combination of different sources.

The major benefit of the participatory approach from a cartographic perspective, however, is that qualitative data can be gathered in addition to the quantitative measurements. This combination has the potential to result in information that is nearer to the day-to-day experience of citizens. The approaches to collect additional qualitative and, therefore, subjective data differ and are improvable with respect to their further use. *NoiseTube* measurements can be tagged. However, an interpretation of these annotations can be complex, requiring a linguistic analysis (cf. Hauthal and Burghardt 2014). *WideNoise* additionally allows to qualify the noise events on the scales love or hate, calm or hectic, alone or social, and nature or man-made by means of sliders. The latter leads to classified results that are useful for further interpretation and visualisation.

9.5 Conclusion

The author has presented an overview of characteristics of noise and the sound pressure level relevant for the visualisation in maps. With this in mind, the author has discussed selected aspects of cartographic presentation in END-conform as well as crowdsourced noise maps. The latter are especially seen as a source of qualitative information that could complement authoritative noise maps and enhance the understanding of noise.

EU directives about noise information lack concrete guidelines for the graphic presentation, which results in heterogeneous presentations throughout Europe. Although a certain degree of freedom is appreciated by agglomerations and federal states that are responsible for noise mapping, from a user-perspective it often results in a lack of quality. This is especially problematic as the harmonized indicators used for strategic noise mapping, the A-weighted long-term average sound level L_{den}, is hard to comprehend for laypeople. Major challenges, as described below, are rooted in acoustic and psychoacoustic principles and the difficulty to reflect these principles in the visualisation:

- The continuous value presented in maps does not reflect diurnal changes and citizens' day-to-day experiences that are amongst others characterized by intermitted noise events for e.g. aircraft noise.
- Sound pressure level is a logarithmic measure. Therefore, higher values contribute more to a mean value. The equidistant 5-dB-classes do not reflect this. A solution is to increase saturation for higher values and thereby highlight them in contrast to low values.
- While the SPL is the objectively describable measure the human ear is sensitive for, the perception of loudness is a result of several parameters, such as frequency. Nevertheless many map users suppose that noise maps present what they perceive as loudness. The subjective perception of loudness, however, is very different to the SPL: An increase by 10 dB results in a doubling of loudness, while a 10 dB decrease results in a halving, i.e. a rise from 80 to 90 dB has major consequences that are not apparent to laypeople on the basis of current maps. Therefore, the author stimulates a discussion about what kind of further information would be necessary to reflect people's day-to-day experiences.

The alternative colour scheme the author introduced exemplifies how the (psycho)acoustic aspects described above can be represented by means of visual variables. The author applied a strong increase of saturation in combination with a decrease of lightness to highlight levels of high noise exposure and hotspots. Colour as the major visual variable for the representation of traffic and rail noise is crucial for an intuitive understanding of the information.

However, the special characteristics of noise cannot be reflected by *one* indicator, as the following quote highlights for aircraft noise: "[. . .] aircraft noise can vary in terms of its magnitude, frequency and duration for each noise event, and also for how many events occur in a given time period. Portraying this information in a single indicator is an inevitable compromise. No single indicator can fully describe the noise exposure at a given location" (Airports Commission 2013b, p. 25). Further research is needed to define which parameters really reflect day-to-day experiences of affected people and how these parameters can be visualised additionally to L_{den}. The author would like to suggest a pragmatic approach here and encourage to integrate additional information into noise maps like thematic map-layers, diagrams, or infographics. This information could be of great benefit to highlight aspects of a specific, regional noise environment, while a general comparability would be supported by means of official noise indicators. Especially for interactive noise maps the integration of additional information does not need much effort.

This article focuses on the cartographic presentation and outlined cartographic aspects of authoritative as well as crowdsourced noise maps, comparing modes of presentation based on the data format. Aspects of quality for crowdsourced data were considered with regard to cartographic presentation, while data quality of authoritative noise modelling was assumed. Thereby the author followed an applied, pragmatic approach instead of initiating a discussion about who has the right to claim expertise in noise mapping (see C. Regalado, this volume), citizens who experience noise on a day-to-day basis or authorities who apply an "objective" approach (cf. Kerr et al. 2007; Wynne 1992). The author argues that strategic noise maps can be enhanced by adding information that reflects firstly the characteristics of noise and secondly how noise is perceived. The method of crowdsourcing is a promising method to collect such data, as long as it is used transparently and data format and quality are considered in the cartographic presentation. The combination of authoritative and crowdsourced information holds great potential. The latter is especially suitable to contribute to a subjective perspective.

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Chapter 10
Usability and Interaction Dimensions of Participatory Noise and Ecological Monitoring

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10.1 Introduction

The integration of sensors in smartphones has transformed personal mobile phones, from tools primarily meant for communication purposes, into instruments that can sense or collect information about the surrounding environment (Lane et al. 2010). There are several mobile apps that allow ordinary members of the public (non-professionals) to collect fine-grained data about their environment and to contribute to real research. By involving citizens in environmental monitoring activities this helps to raise their awareness of environmental issues (Becker et al. 2013). However there are also challenges in the use of such apps. The lower-end sensors for mobile phones do not give the same level of data accuracy as specialised devices. The data is being collected by 'inexpert' citizens, which may add to perceptions of the data being inaccurate. Also, in order to apply complex statistical models, the data needs to be collected in mass quantities. This raises two questions about the citizens involved: (1) what is their experience of using the app and (2) what factors motivate them to participate?

In this chapter we describe field studies where we tested two kinds of environmental monitoring apps—noise monitoring apps (WideNoise, NoiseWatch) and ecological monitoring apps (iSpot, Project Noah, UK Ladybird Survey). These studies were conducted with the aim of uncovering factors that acted as barriers to data collection and to identify design opportunities that could sustain user contribution. It was important for us to conduct our studies 'in the wild' (outside of the lab) as we wanted to understand the factors that affect how a person uses a technology within a natural context (Rogers 2011). For both studies, participants

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tried out several apps in various locations around London. For the noise monitoring study, participants additionally took part in a 6-day diary study, where they reflected on their experience of using (and not using) the apps during their day-to-day lives. In the following sections we will describe the aim, methodology and findings of each of our studies. This will be followed by a discussion of the lessons learned.

10.2 Noise Monitoring

Environmental noise is defined as "the noise cause by traffic, industrial and recreational activities" (European Commission 1996). It is estimated that approximately 20 % of the EU population (80 million people) are exposed to daytime noise levels above 65 dBA and that another 170 million people live in areas with noise levels between 55 and 65 dBA (European Commission 1996). As a result of urban noise pollution, approximately 25 % of the EU population suffer from a deterioration of life quality due to annoyance, and between 5 and 15 % are affected by sleep disturbance (European Parliament and Council 2002). To tackle this problem, the EU issued the European Noise Directive. They aim to establish a noise management policy, which includes generating noise maps every 5 years to monitor the levels of noise generated by road, air and rail traffic, as well as industrial facilities. However this approach is limited because it does not provide a fine-grained view of actual exposure to environmental noise; it is based on simulation models based on noise samples collected in limited areas (Stevens 2012).

Advocates of participatory noise mapping argue that if enough citizens could be encouraged to go out and collect noise readings, then this could provide the more fine-grained level of data that is needed. There are currently several mobile phone apps for noise detection that have been developed and made available to download free of charge. In our study we decided to test two apps: NoiseWatch and WideNoise.

NoiseWatch is an app developed by the European Environment Agency. NoiseWatch presents a simple interaction focused on recording and submitting noise samples. A category selection list is provided and the user is tasked with classifying the noise heard: air traffic, road traffic, rail traffic, industrial activities, or 'other'.

WideNoise is an app developed by a consortium of academic and research institutions. WideNoise presents a more complex design than NoiseWatch, involving more steps for noise sampling and submission, but it also offers a more personalized experience. Users can guess the noise level while the measurement is being carried out, with the aim of teaching users to learn to identify the dB level of a noise. Users have the option of providing subjective feedback on their personal perception of the noise (e.g. love/hate, calm/hectic, social/alone). Users can add tags to express sentiment, or to provide more details about the place or noise source. It is also possible for users to create an online account where their personal contributions are displayed on a map and there are several graphs that show their contribution history and other data.

However not much is yet known about the experiences of the people that use these apps. Furthermore, previous research has focused on special interest groups that are highly motivated to participate—for example, members of a non-profit environmental organisation (D'Hont et al. 2012) or residents that lived near Heathrow airport (Becker et al. 2013). We suggest that it is important to sustain a wide pool of citizens' contributions in order for the participatory noise paradigm to be effective. Therefore in our research we decided to recruit participants that only had a minimal/moderate interest in noise issues. We investigated participants' experiences of two apps (NoiseWatch, WideNoise) with the aim of uncovering factors that acted as enablers and barriers to data collection, and identifying design opportunities that could encourage contribution.

10.2.1 Methodology

Initially we distributed a survey to 60 residents of London and surrounding areas, to gauge their interest in noise and environmental issues. These participants were recruited via an opportunity sample. Based on our survey data, we identified three types of contributors that could be good candidates for participatory noise mapping:

1. People concerned about noise effects on health, driven by personal interest;
2. People sensitive to noise, driven by personal interest and contribution purposes;
3. People already manifesting a pro-environment behaviour, driven by contribution purposes.

The survey respondents that most fit these criteria were invited to take part in our field study. We recruited 18 participants in total, four male and 14 female. Their ages ranged from 21 to 60 years (mode age category = 21–29 years). Regarding occupation, nine were professionals and nine were students.

The 18 participants were instructed to install two noise monitoring apps—NoiseWatch and WideNoise—on their personal smartphones. Seven participants installed the apps on their iPhone. Four participants installed the apps on Android smartphones. The seven remaining participants owned other kinds of Smartphones (e.g. Windows, Blackberry, Nokia) that were not compatible with the app. These participants were given a Samsung handset with the apps already installed.

The first part of the study was a 1-h field experiment. Ten participants performed the first part of the study in a workshop held at a London university campus; this involved testing the app in the streets surrounding the university campus area. The other eight participants executed this part of the study by themselves because they were unable to attend the workshop; this involved testing the app outdoors on streets close to where they lived or on their journey to/from work. The researcher instructed all participants to test each app for 30 min each. To counteract order effects, half of the participants tested NoiseWatch first, and half of the participants tested WideNoise first. Participants were instructed to walk around the campus (around nearby roads) and to voice record their observations (using the voice recording app on their phone). Participants were also given a checklist of items to act as a prompt. This list included items such as: context in which the measurement was carried out, the experience of taking samples on the street, things that they found pleasant/unpleasant, easy/difficult, clear/unclear, etc. After the 1-h field experiment, participants reconvened with the researcher for a brief discussion of their experience. All participants were rewarded with a small gift voucher (£5) for taking part.

The second part of the study was a week-long diary study. The 18 participants were instructed to use the two apps for three consecutive days each and to voice record their observations daily. Again the order of which app to use first was counterbalanced amongst participants. Participants were instructed to send their voice recordings to the researcher every 2 days and in the event of a delay, the researcher sent the participant a reminder. At the end of the week, participants took part in a brief interview (in person or via Skype). We also held a raffle draw, where 1 participant was selected at random to receive a £50 gift voucher.

Participants' voice recordings were transcribed and analysed using Thematic Analysis—a qualitative method for identifying, analysing and reporting patterns (themes) within data (Braun and Clarke 2006). Our themes include: user interface, sense making, technology, lifestyle and motivation.

10.2.2 User Interface

Participants desired a fast interaction, good user interface contrast, visible controls and a low number of steps for taking and submitting noise data. Being able to express subjective perceptions of noise was also a desirable feature, and as a result the majority of participants preferred WideNoise over NoiseWatch. But at the same time, WideNoise involved more steps for noise sampling and data submission, which could prove problematic when trying to collect data on-the-go:

> I just took a sample on a busier street, I kind of had to sit down and concentrate a bit more as I was using it in public. The other places I was before were much quieter and I could sit and take my time, so that was a little frustrating but I enjoyed the features, though I felt a bit rushed through them. [F27, WideNoise]
>
> In some places especially with this app it takes so long! So I can't just quickly sample it. [M28, WideNoise]

Other problems encountered by participants included screen glare in the sunlight, poor contrast, small labels and fiddly controls. For example, in Fig. 10.1 we can see a participant using a sheet of paper in an attempt to shade the phone screen from the sun.

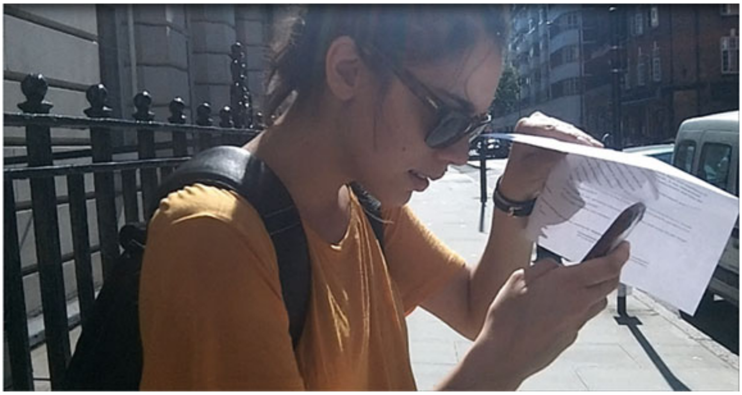

Fig. 10.1 A participant using paper to overcome screen glare from the sun

10.2.3 Sense Making

The use of dB numeric values was not particularly meaningful to participants. Several participants said that they would have liked to see a comparison with noise levels detected in other areas, or a history of their personal measurements. This would enable them to make inferences about their personal exposure to noise, as well as information about the effects on health of the exposure to those levels:

> I do not really know if 52 dB is good or bad. I just know it's a middle range noise. I guess it could give me advice for what side effects there are from being in this kind of level of noise for too long, I don't know, if there are side effects, I have no idea. [F27, NoiseWatch]
>
> I took a measurement when a car was passing by and interestingly the noise level went up to the very edge of good level of noise, 45, which is quite interesting, because this is the type of noise you are going to come across anyway in an urban environment with traffic, so obviously it's questionable whether it is good for your health to live anywhere near road traffic. [F33, NoiseWatch]

We suggest that a re-examination of how to best represent real world noises in the apps is needed. The current dB level categorization into 'good' and 'bad' is based on dB levels causing hearing damage. Typical dB levels in urban environments are lower; however they can still cause 'annoyance' and potentially affect a person's wellbeing over a longer period of time.

Another finding was that the classification of noises into a limited number of categories, as in NoiseWatch, clashed with the variety of noises people would perceive in the urban environment. Similarly the iconographic set of noise types provided in WideNoise, automatically matching an icon to a noise recording, was perceived as unsuitable on several occasions:

> The main noise is coming from the air conditioning and WideNoise has identified air-conditioning as a TV which is quite amusing [M36, WideNoise]

Icons are limited because they can be misinterpreted by users and it is difficult to indicate loudness and tonality at the same time.

10.2.4 Technology

Lack of internet connectivity can prevent sample collection and may discourage people from using the apps. Unlike WideNoise, NoiseWatch does not allow you to store samples and upload them at a later time when connection becomes available again or over a WiFi connection. For this reason, two participants did not use NoiseWatch during the week-long diary study because they were unwilling/unable to consume their Internet data allowance.

Participants also expressed concerns about the GPS activation relative to battery consumption. In some cases participants decided to disable the GPS:

> I feel reluctant to open the GPS because it tends to consume the phone battery, so I chose not to use the GPS. [F34, both apps]

10.2.5 Lifestyle and Motivation

Lack of time, routine, and forgetfulness were identified as barriers for sustained contribution. Ten participants said that they had a routine lifestyle and once they collected noise samples along their daily routes they would not feel motivated to carry on sampling because of the lack of sense of discovery:

> So far, most of my samples have got the car and the feather icon, so after several measurements I find this becomes a bit boring, because I do not get the chance to guess others, because I do not go to places where they have higher or lower levels of noise. A bit of variation would be good. [F34, WideNoise]

Five participants talked about how they found themselves forgetting to take noise samples:

> I almost forgot to use it, and I kind of set up the alarm to remind me to use it. It's just very easy for people to forget to use it, well for me, I don't see too many opportunities to use it. [F28, both apps]
>
> The best time I have found I'd be able to take a noise sample would be when I am waiting, for example at the train station, that's the only place I find I am able to spend time to do so. [F34, both apps]

Finally, five participants listed amongst the reasons for not being likely to continue the activity the fact that they did not see how their contribution could make a difference. In line with previous research (Rotman et al. 2012), this suggests that there are different motivational factors affecting initial interest and sustained contribution. Users need compelling reasons to motivate them to continue taking noise readings over a long period of time.

10.3 Ecological Monitoring

The second type of activity that we explore here relates to ecological monitoring, specifically, monitoring within the field of biodiversity. In this context, the concept of 'biodiversity'—the number, variety and variability of organisms living in a certain area—plays a major role. Monitoring biodiversity is important because it allows conservationists to keep track of changes in a population. Involving members of the public in monitoring activities can help in raising awareness of ecological issues, scientific processes and the importance of conservation.

Contextual observation of two 'BioBlitz' events helped lay the foundation for the user evaluation. A BioBlitz is an event where members of the public are encouraged to participate in ecological citizen science. It takes place within a defined geographic area and over a 24 h time period. They are organised as a series of walks or activities, for example bird walks, fungi forays, stream dipping, and butterfly walks. These events, led by subject matter experts, local and familiar with the ecology of the area, offer an opportunity for non-experts to gain experience of species identification and data collection.

We observed two BioBlitzes in the UK—one in Gloucestershire and one in Surrey organized by Natural England and Sutton Ecology Centre respectively. It was commonplace for experts to use paper-based forms to mark down their sightings and these forms were then handed to a data entry team. By contrast, novices took on a more passive role and did not collect any data themselves. We suggest that mobile technology could provide support for data collection to novices in the field. Firstly, it enables users to collect and submit data immediately rather than finding time post event to submit. Secondly, if designed appropriately, mobile technology could provide support for novices with species identification during data collection.

There are currently several mobile phone apps for ecological monitoring that are available to download. In our study we decided to test three apps: Project Noah, iSpot and UK Ladybird Survey. As was the case in noise monitoring, not much is yet known about the experiences of the people that use these apps, particularly the experiences of novice users. In our research we investigated participants' experiences of using these apps, exploring whether such apps supported novice users to engage in biodiversity monitoring.

10.3.1 Methodology

Twenty-three participants were recruited via an opportunity sample. Seventeen were female, six were male, and their ages ranged from 24 to 64 years (mean = 42.9, SD = 13.5). They were all novices, as they had never taken part in ecological monitoring before. They were tested in ten groups and the groups met at Hampstead Heath or Richmond Park. These are large open heathland areas, covering 790 acres and 2360 acres respectively. Weather conditions ranged from very hot bright weather to thunderstorms. The researcher explained the purpose of the field study and gave each participant a Samsung Galaxy XCover mobile phone, where the apps were already installed. The order in which the apps were tested was counterbalanced across the 10 groups in order to counteract any order effects.

All three apps had distinctive approaches to the process of engaging users in data collection process. There were two multi-species apps: Project Noah, a US-developed app; and iSpot, an app developed by the Open University in the UK. To successfully complete a record, the user needs to take a photo, move through a series of data fields and tabs, locate the sighting and then submit to the 'community' for expert identification.

The third app was the UK Ladybird Survey, which was developed by the University of Bristol and the Centre for Hydrology and Ecology. This is a single species app that uses a different process for identification and validation, because of the small number of ladybird species and the relatively distinctive look of the insect. Identification is made by the user who compares their photo with that of the 23 species images stored by the app. The data record is then submitted to project scientists who validate the record.

The researcher asked participants to complete a range of tasks using the apps, for instance, to make a 'sighting' and submit. Participants were also asked to explore other features of the apps to understand their role in supporting data collection functionality specifically the 'mission' and 'reputation' elements of Project Noah and iSpot respectively and whether they helped encourage participation. Testing sessions lasted approximately an hour and were followed by a focus group discussion.

The focus group discussion was audio-recorded. Recordings were transcribed and analysed using Thematic Analysis (Braun and Clarke 2006). Our themes included: image quality, screen visibility, connectivity and GPS, and manual entry of the location and landscape.

10.3.2 Image Quality

The photo is core to all these apps. Image quality therefore is paramount for identification purposes. However the Samsung handset did not take close-ups or enable users to zoom. Although the study did not look at other models, it is likely that this will be an issue across most mobile phones. Users found this highly problematic, complaining of fuzzy images and the camera being too slow, i.e. the animal or insect had moved or the surface the insect was on moved, light levels were too low. As many of the subjects such as ladybirds are small, they require a close view for successful identification. The app itself did not enable zooming and this, forced users to work around the app in their attempt to identify the species. For example, in Fig. 10.2 we can see a participant using the UK Ladybird Survey app, trying to identify the ladybird by referring to the actual ladybird, rather than the photo that he/she had just taken.

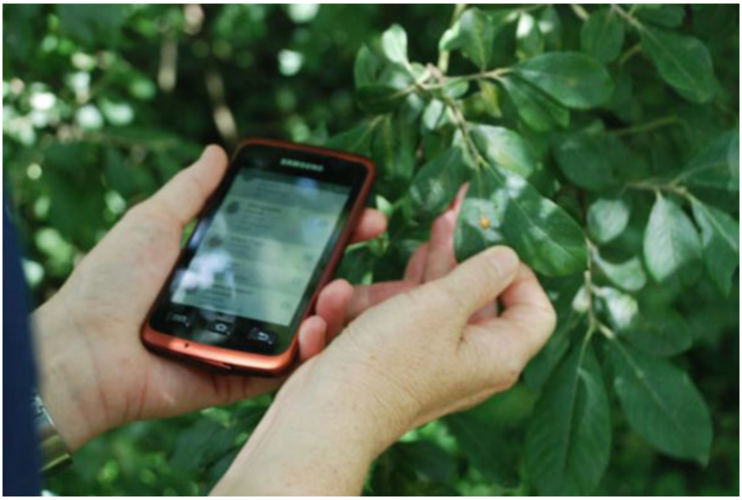

Fig. 10.2 A participant referring to the ladybird, rather than the screen image, in order to identify it. This is because the screen image was poor and sunlight reflected on the screen reducing any ability to view the image

Fig. 10.3 Viewing an image using a digital SLR camera during a Bioblitz. The camera was mounted with a 500 mm lens—this enabled the user to get a clear shot of the subject

In our contextual observation of the Bioblitzes we had observed experts using SLR cameras mounted with 500 mm lens and using rapid continuous shutter functions in order to get the desired picture of their sightings, see Fig. 10.3. Enabling users to achieve a similar functionality using a mobile phone app presents an important challenge: it is assumed that anyone with a smartphone can take photos and contribute data, however some images may not be of a good enough quality for species identification.

10.3.3 Screen Visibility and Technology Use

Direct sunlight hitting the screen reduced readability immensely and prevented effective use of the apps. This problem was exacerbated by interface designs that used small icons or required the user to switch through a number of small fields or tabs as part of the sequence of data entry, often leading to frustration. Rain was also a threat to data collection as mobile phones are not designed for the purpose of outdoor data collection. There was also ambiguity with the role of technology within data collection practices—while some participants clearly brought expensive equipment to the field (such as SLR), they seem reluctant to use smartphones or tablets in their field work. This might be due to the perception that the equipment is not robust enough or due to the context of use (as it is seen as interfering with the experience in the field).

10.3.4 Connectivity and GPS

Identifying an exact location for mobile devices depends on GPS signal. Waiting for a signal proved frustrating for many users who were faced with a revolving pre-loading icon for extended periods of time. This, with added absence of connectivity, meant sending a precise record was impossible.

App design does not help resolve these issues. If the Ladybird app specifies that finding a location will not take more than 2 min and the user is there for at least five, then the user is likely to find waiting frustrating. If the app requires the user to sign in at the last minute in order to send a record, as the UK Ladybird Survey does, and which in the absence of a connection appears to cause the app to fail then it is not surprising that the user becomes confused, frustrated and angry. For example, one participant complained:

> So everything's gone, lost. It's not right you do all your study and you put all the information in and you get stuck because of the *** application. It's a most frustrating thing!

10.3.5 Manual Entry of the Location and Landscape

Location presents further complexity as the user is required to name the type of landscape. Participants described feeling uncertain whether they had entered the data correctly. For instance, is Hampstead Heath 'grassland' or a 'park'? What is 'heathland'? This information was, for instance, requested by iSpot.

Some participants could not understand why they needed to determine location with many suggesting that landscape/location functionality should be a background operation. In addition, some participants didn't understand why location needed to be part of the sequence of data entry at all, thereby misunderstanding an essential and fundamental requirement of ecological monitoring.

10.4 Discussion and Conclusions

Mobile sensing apps allow citizens to contribute to environmental monitoring research. However, as our studies revealed, there are several barriers to data collection. Technological factors, such as lack of connectivity, can prevent sample capture and lead to user frustration. Enabling storage and a 'send later' function (like WideNoise does) is one way to overcome this problem and can be significant in citizen science projects that require environmental monitoring; however this also places memory load on the user as they need to remember to send the record later. Enabling automatic submission when connected to a Wi-Fi network or 3G/4G service is another possible solution; but limited in that accurate geo-localization data of the samples might not be available.

Environmental factors can also present barriers to data collection. Participants found it difficult to take noise samples on a busy street if the app involved too many steps. Weather conditions, such as the sun and rain, affected the screen visibility and the ease at which data could be collected.

Crucially, we argue that many of these insights were only possible because we conducted our research in the wild (Rogers 2011). By testing the noise monitoring apps around the university campus, and testing the ecological monitoring apps in open heathland areas, we were able to uncover participants' experience of the apps within an intended context of use. Additionally, the 6-day diary study gave us insights into participants' experience of using (and not using) the apps within their day-to-day lives. Lifestyle and motivation factors, such as lack of time, routine, and forgetfulness, were identified as barriers for sustained contribution.

Conducting research in the wild is not an easy task. It can be difficult to recruit participants and to sustain their motivation over a long period of time. We found it helpful to recruit participants with a minimal/moderate interest in environmental issues. We also found it helpful to offer participants a small reimbursement for their time and to send diary participants regular reminders.

In future research it would be useful to investigate ways of sustaining citizens' participation in environmental monitoring activities. Based on our findings, we recommend emphasising how each person's contribution makes a difference and allowing participants to track their individual progress and the project's progress. Using the persuasive design literature as inspiration (Fogg 2009), researchers could implementing different 'triggers' to prompt citizens to contribute, exploring which trigger participants like best. Furthermore, it would be useful to explore the impact of social motivations (Rotman et al. 2012). In our study of BioBlitzes we found that novices viewed it as a fun day out, where they could meet other people and learn more about nature. Similarly, we recommend that if environmental monitoring apps were designed to help citizens meet up and collect data in groups, and encouraged citizens to interact with each other, it is possible that social factors could play a strong role in sustaining participation.

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Apps

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UK Ladybird Survey. http://www.ladybird-survey.org/

WideNoise. http://www.widetag.com/widenoise/

Chapter 11
Participatory Sensing: Recruiting Bipedal Platforms or Building Issue-centred Projects?

Christian Nold and Louise Francis

11.1 Introduction

In the last decade, participatory sensing has gained importance by aiding scientific research and supporting urban decision-making as well as emergency disaster response. This approach has many names: participatory sensing (Burke et al. 2006), urban sensing (Campbell et al. 2006), citizen sensing (Paulos et al. 2009), human-in-the-loop (Sheth 2009), human-centric sensing (Srivastava et al. 1958), people-centric (Eisenman et al. 2006) or community sensing (Krause et al. 2008). There are also many overlaps with the literature from citizen science (Silvertown 2009) and crowdsourcing (Brabham 2008). This paper focuses on the application of participatory sensing in the context of environmental monitoring. Classically, environmental monitoring functions to support policy and decision-making, via highly calibrated sensor stations that autonomously collect data about the environment. In contrast, participatory sensing promises mass participation of the public, who use their own hardware to collect large quantities of somewhat lower quality data. There are now a number of established academic fields that examine the technical challenges of this type of sensing, in particular how to maximise data quality and quantity. In contrast, the role of the participants, their recruitment and the methods for managing sensing campaigns are rarely discussed or analysed in the literature. In particular, the amount of work involved in setting up sensing campaigns and the impact of particular campaign choices are frequently downplayed. The goal of this paper is to analyse and reflect on the assumptions of participatory sensing via an empirical case study.

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11.1.1 The Assumptions of Participatory Sensing

The starting points for this paper are a series of implicit assumptions of participatory sensing. The statements are broad brushstrokes that synthesise the way in which the literature conceptualises the role of participants and the suggested methods for dealing with them. The practicalities of participatory processes are important to us since we are both participatory practitioners who have initiated and managed large scale community sensing projects with thousands of participants over the last decade. As well as this practical experience, our analysis also builds on a social science perspective that has been examining scientific work within laboratories but is now paying attention to the environmental practices of science involving volunteers (Ellis 2011; Lorimer 2008). The reason we focus on the assumptions of participatory sensing is that they are very important in dictating the scope of this practice, yet they are not openly discussed. The assumptions describe a blinkered technology-centred notion of participatory sensing, which we argue, misrepresents the actual sensing practices that take place on the ground with participants. The aim of this paper is not to make a case for humanist sensing but to present a pragmatic and realistic portrayal of the complex interactions between humans and technologies. In the act of summarising the assumptions we will inevitably loose some of the exceptions and nuances of these arguments. However, we hope that by identifying them in an explicit way, we can start a discussion about the kind of participatory sensing that we need in order to build a more inclusive and sustainable future.

11.1.1.1 Everybody Has a Smartphone

A key argument used throughout the participatory sensing literature is that smartphone adoption is growing everyday and that they are now ubiquitous across the world. The literature re-uses a range of estimates, including the estimate that there are now one billion mobile phones in use globally (Honicky 2011; Resch 2013; Tilak 2013). The argument is that smartphones have increased computational power (Boulos et al. 2011), network connectivity and flexible data plans as well as embedded sensors, such as a microphone, gyroscope, camera, accelerometer, and GPS receiver. Estrin et al. evocatively describe them as *"imager-microphone-wireless-sensor packages that we all carry on our belts and in our pockets"* (Estrin 2007, p. 3). Paulos suggests that we are witnessing a fundamental transformation of the mobile phone from a personal communication tool into a *"networked mobile personal measurement instrument"* (Paulos et al. 2009, p. 414). While in the western world there has certainly been an increase in the public visibility of smartphones as a desirable object, we suggest that there is a need to examine how evenly this technology is distributed, and to conduct ethnographic research on the actual everyday practices that are enabled by these devices.

11.1.1.2 The Environment is Measurable and Modular

Participatory sensing is premised on the collection of large data sets. The key concept is the notion of the data point, which through digital sampling transforms the continuous flow of the world into a set of discrete entries in a database. These entries share properties such as timestamps and spatial coordinates, which allow data points from different devices and users to be aggregated into a single dataset. Participatory sensing conceives of environmental sensing as a distributed digitisation task that can be reassembled as a dataset of the 'environment'. The assumption is that by collecting vast amounts of data, that ever more detailed and accurate representations of the environment can be produced. A metaphor might be an attempt to build high resolution maps of the world like Google Earth by organising every single human on earth to use their own flatbed scanner to digitise their surroundings. Would the resulting data create a meaningful representation of the environment? At the heart of participatory sensing is a belief that mass quantification is the primary way of gaining knowledge about the environment. Yet it is worth considering the limits of this method and questioning what other means of engaging with the environment might be sidelined by this approach.

11.1.1.3 Crowdsourcing Provides Free Labour and Technology

Participatory sensing typically uses the notion of crowdsourcing (Letts 2006) and micro-tasks. This involves breaking-down large scale problems into smaller modular tasks that can be outsourced to a large number of external workers. The idea is that participatory sensing can gather large amounts of distributed data beyond the few expensive sensor stations that are currently used for environmental monitoring. Thus running these projects becomes an organisational and managerial task of encouraging people to participate and making sure there is enough coverage to create continuous datasets. This outsourcing also extends to the sensor hardware itself. While smartphones possess powerful sensors, they are not autonomous and they require people to operate them and support them. Even sensing apps that run as background processes and do not require active input from the user, need people to charge the phone battery, pay the bills and make sure that things are functioning properly. Thus the benefit of participatory sensing is that the tricky tasks of power management, network formation and maintenance (Honicky 2011) are handed over to the phone's owner. From a researcher's perspective, crowdsourcing seems to offer enormous savings in terms of labour and hardware costs. The assumption is that it is possible to achieve a successful and stable division of labour with the researchers defining problems and creating technologies, while the participants carry out repetitive tasks using their own smartphones, exactly as instructed. Yet crowdsourcing does not acknowledge the range of costs and impacts associated with this model of sensing, in terms of participant and researcher labour and material practices.

11.1.1.4 People are Less Reliable than Technologies

Throughout the participatory sensing literature, participants are often described as **MULEs** (mobile ubiquitous LAN extensions) (Bhadauria et al. 2011; Ganti et al. 2008; Shah et al. 2003; Tseng et al. 2010; Wu et al. 2009; Yang et al. 2013). This term describes 'platforms' that provide mobility for technical sensors and allow them to cover larger areas. The term MULEs does not differentiate between animals, humans or moving machinery, since they can all transport sensors. In this vision, the assumption is that sensing is purely a technical activity. The sensor is a piece of technical hardware that is separate from the MULE itself; see Fig. 11.1. In this vision, the role of the human is merely to act as a bipedal sensing platform that facilitates the sensor technology. In fact, participants are often seen as a point of failure that can inhibit the technical sensor by introducing inaccurate or malicious data (Yang et al. 2011). Wang et al. argue, that *"unlike well-calibrated and well-tested infrastructure sensors, humans are less reliable, and the likelihood that participants' measurements are correct is often unknown a priori"* (Wang et al. 2011, p. 7). This approach to participatory sensing presupposes

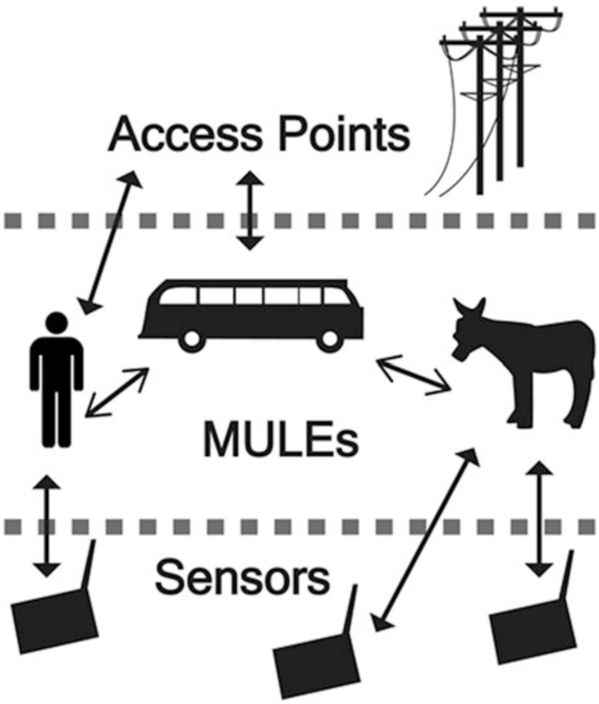

Fig. 11.1 Illustration from Shah et al. (2003) showing the notion of MULEs as human/animal/machine platforms that are distinct from the sensors themselves. Note the *dotted line* which visually separates MULEs from the sensors

that the technological sensor is de-facto 'correct', while humans are unpredictable. In order to standardise the behaviour of participants, the literature suggests rigorous (Dickinson et al. 2010) and differential protocols, which, for example, allow skilled volunteers to count every bird, while less skilled ones are restricted to counting the most easily recognised (Cohn 2008). The assumption is that there is a single scientifically/technically correct way of gathering data about the environment that is embedded into technical protocols. This creates an apparent chasm between researchers' notions of data quality and the way in which participants are imagined to behave. In effect, participants are not involved in setting the agenda with regards to what or how the environment might be sensed. Our concern is that this approach to sensing excludes the ways in which humans experience and interact with the environment and it also dictates the kind of phenomena that can be sensed. The environment becomes defined as those phenomena that the researchers deem valuable and which the hardware sensor can measure. How does this sidelining of human capacities, such as recognising, interpreting and acting within physical and social contexts shape environmental sensing?

11.1.1.5 Motivation is a Universal Property

As we noted earlier, for practical reasons, crowdsourcing is reliant on people's participation. One of the key discussions within the participatory sensing and crowdsourcing literature is how to attract people and maintain their active participation (Massung et al. 2013). The literature summarises this problem via the notion of 'motivation', as a range of internal factors that are seen to dictate people's participation. One area of discourse uses behavioural psychology (Nov et al. 2011; Rotman et al. 2012) to identify essentialist drives that are categorised. The supposition is that motivation is a universal and identifiable property possessed by humans in the same way as their mass in kilograms. Another way in which motivation is conceived is by perceiving people as isolated and economically selfish individuals. There are many papers that propose a data market for participatory sensing, where users are paid for their data points as set by a commercial supply and demand market (Lan and Wang 2013; Luo and Tham 2012; Tham and Luo 2013). Thus 'motivation' becomes an economic model for operationalising users. What these approaches have in common is that they see motivation as an internal property of participants and not as external properties such as the attractiveness of a particular sensing task or process, the quality of the interface design of the sensing device or the recruitment work done by the researchers. What affect does this way of understanding motivation have on the success of trying to recruit participants?

11.1.1.6 Engagement Can Be Automated

Particular gaps within the participatory sensing literature that are worthy of note are the specific methods used to contact potential participants and the manner in which the sensing processes are managed throughout a project. Much of the literature assumes that sensing projects are inherently attractive and will propagate themselves via social media (Boulos et al. 2011) or automated recruitment mechanisms (Reddy et al. 2010). The hope is that projects will go 'viral' and reach a 'tipping point' (Srivastava et al. 1958), and thus will recruit large audiences of participants. There is some detail about how to recruit for online projects using 'game-like contribution channels', 'network coordination services' (Yang et al. 2013) and 'micro-task markets' (Kittur et al. 2008), but there is little detail about how to recruit for participatory sensing. We suggest that participatory sensing is inherently different from online crowdsourcing in that it requires participants to physically carry hardware and sensors whilst transversing outdoor areas. These activities involve learning about the maintenance of hardware sensors as well as requiring significant time commitments to execute the sensing processes themselves. Yet to our knowledge, there are few papers that explicitly address the specific requirements of recruiting participants for environmental sensing and we found only a small number that discuss recruitment methods (Amintoosi and Kanhere 2013; Reddy et al. 2010, 2009; Tuncay et al. 2013). These describe matchmaking systems that use databases of people and their devices to allow matching with the requirements of sensing campaigns. The databases contain details of the *"participants' device capabilities, geographic and temporal availability, demographic diversity, and social network affiliation"* (Reddy et al. 2010, p.140). It is unclear how sensitive information about potential participants such as their mobile phone number, location and availability appear in theses databases. Presumably, for such a system to work, the overall project would have to be publicised and individuals contacted in order to gain their consent and to collect the data. Once a match is made with a potential participant they would have to be contacted by telephone or email in order to initiate the actual sensing activity itself. Yet the inter-personal practicalities of how this might be accomplished are not addressed in this literature, which instead focuses on the technical implementation of matchmaking algorithms. Two of the papers Tuncay et al. (2013) and Amintoosi and Kanhere (2013) go some way to offer technical solutions. They propose that once a match is made, a 'recruiter node' (Tuncay et al. 2013) will automatically 'recruit' another phone to join the sensing campaign. Yet how realistic are these ideas? The matchmaking proposals appear to be small scale experiments or conceptual models and scaling them up would increase the need to interact with people in order to determine their availability, hardware and location. It is hard to imagine that large numbers of people would volunteer their personal mobile phone for a project that would take remote control of their phone. To build a global recruitment system with large numbers of users would present a range of problems that are not addressed. We also question what kinds of sensing campaigns actually benefit from avoiding direct interactions between researchers and participants. Can automated recruitment create coherent sensing campaigns where the researchers understand what the participants are doing as they create data?

11.2 The WideNoise Case Study

How does participatory sensing actually function? In particular, how do sensing projects manage to recruit participants? In this section, we explore a case study and model for recruitment that highlights the role of the researcher as facilitator and actively engages participants in sensing. The case study is of a smartphone app called WideNoise (EveryAware 2012), which is free to download for iOS and Android operating systems. It allows users to take sound level measurements, which are geo-referenced using the inbuilt GPS and sent to a server where the data is mapped and displayed for participants and researchers. The app was created as part of the EveryAware project, which was funded under the European Seventh Framework Programme within the Information Communication Technologies theme. The EveryAware project aimed to combine a technological and participant focus in order to use environmental sensing for participant awareness enhancement and behavioural change. The project involved the development of new sensing devices as well as technological platforms for data-processing (EveryAware 2011), which were tested using practical deployments of sensors with participants. The project's focus was to demonstrate the utility of low cost sensors deployed as a large distributed network, the point being that the scale and granularity of 'formal' or 'official' environmental data gathering is currently limited due to the cost of sensors and the resources required for large scale data collection. Using low cost sensors operated by participants was intended to address this cost issue as well as achieving better temporal-spatial coverage than the existing sensor networks can provide. Within the EveryAware project, we were responsible for the 'recruitment and engagement of people'. This meant that our role was to identify ways to contact and enlist as many participants as possible, to execute the participatory sensing process and become data gatherers. This responsibility was assigned to us largely due to our previous experience in participatory projects as independent practitioners and members of the ExCiteS (Extreme Citizen Science) research group, whose work is centred on public participation in scientific research.

11.2.1 An Issue-Centred Approach to Recruitment and Campaign Creation

As we described in the introduction, the EveryAware project incorporates many of the assumptions of participatory sensing. In this section we would like to describe the pragmatic balancing act in which we negotiated the technology-centred assumptions, while setting up an issue-centred sensing project in collaboration with a local community group. We based our approach on a wide variety of literature that discusses participation both theoretically and as practical methods. Within participatory rural appraisal (Chambers 1994) a large body of literature suggests that the role of the researcher is that of a catalyst and facilitator of community research that is carried out by the groups themselves. Participatory action research (Reason and Torbert 2001) highlights the need to shorten the distance between research activity and real world change in order to promote social justice. This approach emphasises the need for the researcher's own personal emotional involvement in the research. Participatory design (Björgvinsson et al. 2012) focuses on collaborative design with collectives of people around matters of concern. Community mapping (Perkins 2007) and community art (de Bruyne and Gielen 2009) demonstrate the complexities of 'working with' and 'representing' communities. In our work as participatory practitioners over the past decade, we have used these ideas to sensitise ourselves to the dynamics of relationships with participants. Based on our experience with sensing projects such as Bio Mapping (Nold 2004), Urban Tapestries (Angus et al. 2008) and Feral Robotic Dogs (Jeremijenko 2002), engagement involves collaboration with local organisations and personal communication with individuals. This approach takes a considerable amount of time and requires flexibility and sensitivity on the part of the researchers/project initiators.

In the context of the EveryAware project, these approaches needed to be balanced with our role of recruiting people in order to generate a large amount of data using the WideNoise app. This pre-defined role precluded full collaboration, which would have involved co-designing a project from problem identification to the final design of a suitable sensing device. Within the project we found ourselves in a position in which we were trying to build a participatory process around a prefabricated device. To do this, we expanded on the work of D'Hondt et al. (2013), Chamberlain et al. (2013), who discuss the possibility of combining community processes with participatory sensing. We took a pragmatist position insofar as various kinds of participation were deemed possible within various contexts, as opposed to the binary approach of participation or no participation. Since we were dealing with a ready-made device, which would be deployed for public use, we had to investigate its capabilities. This involved analysing the technical aspects of the application in terms of the way in which sound level calculations were made as well as the details pertaining to the interface and end-user requirements. All of these aspects would have an impact on what would be achievable with the device in a participatory sensing process.

WideNoise was originally developed by a company to demonstrate the scalability of Internet of Things scenarios and not specifically as a tool for environmental sensing (WideTag 2012). For use within the EveryAware project some interface changes were made, including the introduction of sliders and text fields for 'subjective' data entry. In order to evaluate the accuracy of the application, we performed sound level tests in an anechoic chamber following the test procedure laid out by D'Hondt et al. (2013) to compare the level of accuracy with a calibrated Class 1 sound meter. The results showed that WideNoise produced highly variable results when running on different phone models and offered poor correlation to the reference meter. Furthermore, the app did not display readings in dB(A), but presented an unweighted decibel value. We concluded that any data generated by the app would not be directly comparable to official noise standards and could only provide a rough indication of sound pressure. WideNoise does not support continuous monitoring but is based on brief sound events that are actively and consciously chosen by the user. These features meant that the application had radically different characteristics to those of a traditional noise meter, which is designed to measure sound pressure over long durations and within a narrow and specified error margin. Taking the concept of MULEs into consideration and given the disparity between WideNoise and a class 1, or even class 2 sound meter, it would have been difficult to adopt this notion of participants as bipedal sensing platforms of a technically superior environmental sensor.

While it was obvious from the name choice and visual imagery used on the app's interface that WideNoise was designed to sense sound, its intended usage and protocol scenario were less clear. The application does not make any suggestions about what, where, when or how to measure sound. The interface provided a series of icons including a feather, a sleeping cat, a TV, a rock concert, a dragster and a T-rex (Fig. 11.2). These icons symbolised sound volume rather than suggestions regarding what to measure. In the design of the application, particular attention was given to the aesthetics and user interface to make it quick and easy to take a sound level reading, geolocate it, and upload it to an online map. The interface interaction flow involves the user opening the application and pressing a button to take a sound measurement, which typically takes 5 seconds. During this sampling period, the user can drag a slider on the interface to guess the current sound level. Once the sound sample has been taken the level measured by the device is shown next to the user's estimate and the user is given feedback on the accuracy of their guess such as 'good!' or 'no match'. The user is then asked to add subjective descriptions using a number of interface sliders, textual input via tags, and lastly, to submit the data to the server. The app has a predominant focus on the interface sliders used to rate and tag the sound, which is geared more towards content creation in a social media context as presented in concepts such as 'humans as sensors' (Forrest 2010), 'people as sensors' (Resch 2013) and 'social sensors' (Sakaki et al. 2009). The focus in these approaches is that the participants are creating data that is described as 'subjective' user observations.

In order to understand the usability and usage context of the app, we trialled it with a dozen students and researchers for a number of weeks as well as with a larger group of researchers at a public event and asked them to comment on usability aspects and when or how they might use the app. Their feedback was that the application presented no specific purpose for, or context in which to take sound measurements. Yet on the positive side, the respondents said that the interface was easy-to-use. We hired an advertising company to help develop a marketing campaign in order to carry out a pilot project. Their comment with regard to trialling the app was, *"I sort of felt - is that it? It has gone off somewhere but I have no understanding what I have participated in"*. We concluded that the app by itself without any other contextual information presented the act of taking a noise measurement as an arbitrary and meaningless exercise. Based on the formal user feedback and a test campaign by the advertising company, we recognised that if we simply promoted the app on its own it would be extremely difficult to recruit large numbers of people to use the application over a sustained period of time.

WideNoise has unique properties that make it very different from a traditional environmental noise monitor. In order to recruit people, we took into account these

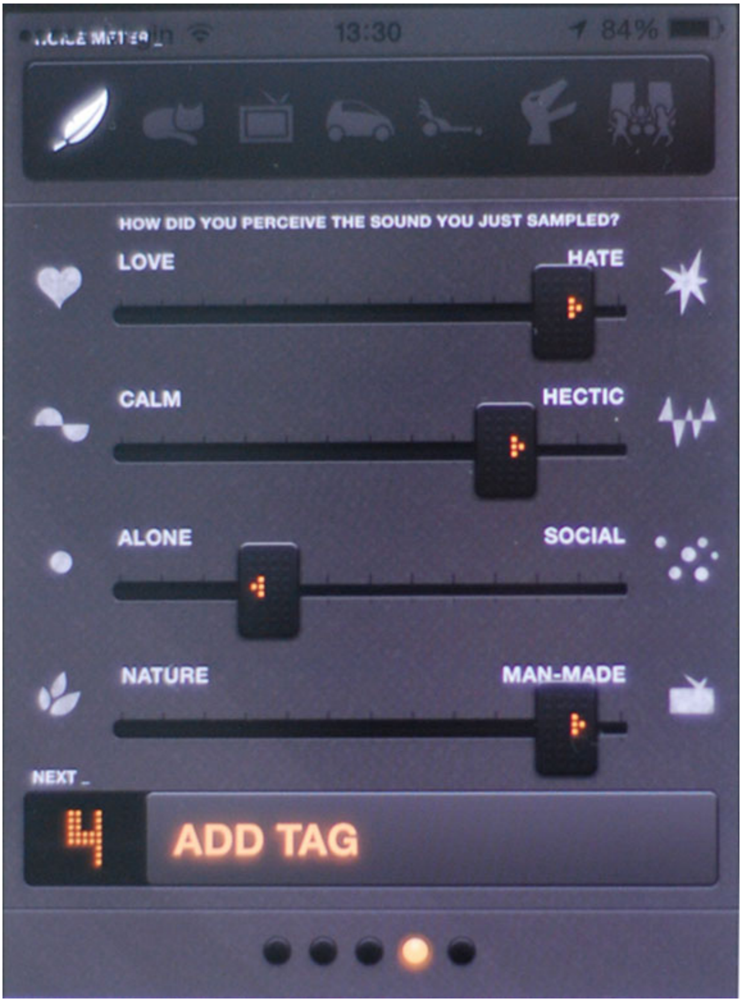

Fig. 11.2 WideNoise interface sliders that allow user to rate the sound measurement they have just created

properties and tried to intertwine them into a narrative that we could communicate to potential participants. We went through a period of brainstorming and design in order to create a sensing process that would encase WideNoise within a broader conceptual framework in which individual sound recordings would contribute towards a larger purpose. We tried to construct a reason for participants to take measurements—something that would make a sound measurement worthwhile and that would make sense of the numerical decibel data. Rather than framing sound simply as a measurable property of the environment, we focused on sound as having an explicit source. This shifted the concept of the environment away from abstract data towards the dynamic interactions between humans and non-humans. In this approach, sound has a 'source', which people can be affected by. It becomes more than sound pressure; it becomes noise and an issue and has an emotional dimension as well as a decibel value. We hypothesised that in this way sound might function as something that people gather around. By framing WideNoise as an issue, we felt that it would be easier to recruit people who were already affected by sound. We considered a number of potential contexts, including neighbour noise nuisance, wind farms or aircraft noise. We chose the issue of aircraft noise around Heathrow Airport in London as the context for our pilot, since it was a broad and public issue that we could use to assemble a collective of people. The airport is an emotive and political issue for local people, which we hoped would enable us to gather a group of engaged citizens for our sensing campaign. It is worth pausing at this stage to acknowledge that by choosing this context we effectively defined what the WideNoise app would be sensing. While we did not dictate or suggest that people should monitor airplane noise, targeting that specific area of London with an application capable of measuring sound invariably led to a major focus on aircraft noise. We let the design of the app and the requirements of the EveryAware project direct us to a context where sound would have meaning for a collective of potential users.

In line with the literature on participatory research, we created the campaign by identifying a local organisation and elected to work with Heathrow Association for the Control of Aircraft Noise (HACAN 2016), the largest voluntary organisation in Europe campaigning on behalf of people suffering from aircraft noise. We felt that collaborating with HACAN would afford the project greater legitimacy in terms of the noise issue and would attract more participants to the project. It was our view that it would be easier for us to try and attach WideNoise onto an existing issue and an organisation that already had a collective of people gathered around it. There would also be more potential for the project to have a positive impact on the noise issue if we partnered with HACAN. From HACAN's perspective, collaboration with an EU research project created legitimacy and publicity for the impact of noise on the Heathrow area. In terms of recruitment, HACAN supported the project by using their mailing list to circulate details of the project throughout their network. We also managed to raise external funding in order to employ a community officer, who was selected by the chairman of HACAN. This individual had local insider knowledge of the noise issue due to living close to the Heathrow runway and his role was to organise the project with local people. With the community officer we created a campaign, assigned it the name; 'Isleworth Noise Map', and used the HACAN mailing list to invite their members to attend a series of workshops in the Heathrow area.

Workshops are a common participatory method for physically gathering people together for a short period of time. Workshops tend to be hosted in a local public space, often in a municipal building. They do not have any explicit format but tend to be informal gatherings. Usually people are expected to come together for a period of time to listen and then asked to actively contribute with questions and discussion; sometimes workshops involve organised activities. We created

Fig. 11.3 Poster design for the Isleworth Noise Map campaign. Sound is represented expressively as noise waves emanating from a plane flying overhead

custom poster artwork and leaflets to promote the project and invited people to the workshops; see Fig. 11.3. The posters were placed in local shops and other key locations throughout the target area. In addition, we wrote and designed a WideNoise manual that explained how to measure sound using the app and the online noise mapping system that could show personal as well as communal noise exposure. We managed to get mainstream televised news coverage for the campaign as well as radio, print and online newspaper coverage. The launch of the 'Isleworth Noise Map' was attended by the chairman of HACAN and a local politician as well as 40 local people. We explained the wider project of building a collaborative noise map and proceeded to help people install the WideNoise app on their phones. We taught people how to use the application and answered their questions. After this initial workshop we hosted another two local workshops. The project community officer kept in close contact with the participants who had the software installed on their phones and arranged local meetings where he could solve people's technical problems with the app and phone. We also continued the communication campaign with additional mailings and interviews on local radio stations as well as in newspapers. As a result of the campaign the project was adopted by a local council who organised workshops and publicised the project. The council felt that the project was so successful that they used the WideNoise data generated by local residents as the basis for their official response to an important UK governmental commission to make proposals on future airport expansion.

11.3 Reconsidering the Assumptions of Participatory Sensing

In the following section we use the case study to reflect back and examine the ways in which some of the assumptions of participatory sensing played out in practice. We go on to explore whether the case study itself suggests some way of going beyond these assumptions.

11.3.1 Everybody Has a Smartphone

During the face-to-face workshops, it was apparent that most of the local people who wanted to take part in noise monitoring were retired and few had suitable modern smartphones. Amongst those that owned a smartphone, few had ever downloaded an app before. Therefore, in order to make the project possible, we had to purchase twenty new smartphones with pre-paid sim cards and lend them to the participants for the duration of the project. We also had to train people in how to use the Android interface as well as the WideNoise app itself. We found that there were significant interface issues related to the user registration, which made it very difficult to use the application. While people were highly motivated to participate, the challenge of using the app was restrictive. In the participatory sensing literature, there is virtually no discussion about the impact of good or bad interface design or the demographic makeup of the intended users. The emphasis on smartphone penetration within the literature obscures the fact that the world is not solely composed of people with the newest and most expensive smartphones; nor are they uniform in their technical aptitude. This raises questions about the central assumption of participatory sensing, which hinges on the ubiquity and accessibility of smartphones. We question the implicit assumption that only rich and technologically literate people should be able to sense the environment. By making a modern smartphone a prerequisite for environmental sensing, large numbers of potential participants are effectively excluded—precisely those people who are most likely to be affected by pollution and blighted by poor local environments.

11.3.2 The Environment is Measurable and Modular

The case study demonstrates that measuring noise pollution with a smartphone application can garner lots of publicity and attract large numbers of people. Yet this campaign was carried out within the context of a very specific issue where measuring noise became a useful and meaningful exercise for people affected by a particular problem. By taking part in the project they were not simply trying to create large quantities of data for scientific research. Based on our surveys and interviews, the participants conveyed the fact that they were trying to attract public and media attention and create political pressure on representatives, whilst also creating evidence of personal exposure and strength of feeling. While this did not necessarily mean that they were not interested in generating scientific data this was not their main objective. This created some problems for the project, the objective of which was to obtain large numbers of measurements, across multiple grid squares, throughout the day and night in order to collect sufficient temporal and spatial coverage to create noise maps. This was not of particular interest to the participants, whose focus was on the pollution exposure caused by the planes flying directly above their heads. This meant that most of the measurements were taken in people's immediate surroundings, often in their gardens or within their houses, rather than across the expanse of the grid squares. Since they were trying to measure the planes themselves, they were measuring peak noise measurements when an aircraft was overhead. In meetings, the participants started to develop and share their own protocols and notions of rigour, which differed from those of the EveryAware research team. During one workshop discussion, one participant said, *"I think for the future it would be much more important to have the rigour, and the rigour should say first of all we will not average readings. And secondly, there should be an encouragement for people not to record less than 75, or 70 or whatever it is. Because to influence the people to whom this applies, it seems to me they are not interested in the fact we have taken 5000 readings and the average is 76. What's going to influence them is that 10 % of the readings were above 85 or whatever and if we cut out all the smaller readings the data that they will get will get bigger and bigger and bigger"*. The participant argued that special rigour was required to capture the peak noise during the overflight of an aeroplane, and that this was more important than averaging readings, since it would create more political impact and increase the growth of the project and the wider political issue. What emerges from this comment is an alternative conception of how and why to carry out empirical measurements. It also clarifies the fact that the project's protocols for collecting data across multiple grid squares is only one of many possible empirical protocols. We argue that this approach of focusing on peak aircraft noise was also a clear result of the short measuring period allowed within the WideNoise application design. The participants appropriated the affordances of the application in conjunction with their own agenda, in order to use the device in such a way that it made sense of taking noise measurements within the Heathrow context. This case study thus challenges the assumption of participatory sensing, in that data gathering will invariably follow the scientist's notion of how to construct rigorous protocols. A successful participatory sensing project requires a collaboration between researchers, local groups and individuals on developing appropriate protocols and devices that mutually support the goals of the involved parties and their different epistemologies.

11.3.3 Crowdsourcing Provides Free Labour and Technology

The participatory sensing literature assumes that it is easy to crowdsource free labour and technology. In contrast, we would like to describe some of the intricate work involved in preparing the smartphones that were lent to the case study participants. We set out to buy twenty identical smartphones but due to 'security concerns' in UK shops it is only possible to buy a few phones in a single purchase. This meant that in order to buy all of the phones we had to go to multiple shops, which resulted in the phones being registered to a number of different telecom providers. Since we did not want to purchase contracts for these phones, we had to buy top-up vouchers for each phone and for the different network providers. Unpacking each phone from its plastic casing, charging the batteries, and setting it up with a unique SIM card and adding credit took a significant amount of time. We then had to go through the phone system settings to remove extraneous interface elements and set up all of the necessary internet access parameters, which required multiple SMS exchanges with each service provider. We then had to download and install the WideNoise app onto each phone. On the Android platform this requires a valid Google account in order to access the Google Play appstore. This meant that we either had to create a separate account for each phone or use a single account on all of the phones. For simplicity, we opted to use a single account to sign into all of the phones. This skewed the registration data for the number of unique user application downloads. Setting up WideNoise also required a separate registration process with an email address, which also needed to be confirmed. Unfortunately some of the phones did not function properly and had to be replaced and switched amongst the participants. This meant that we ended up with a certain number of registration mismatches between users, user accounts, and phone hardware. These multiple levels of registrations, logins, account details and credit levels made it very challenging to administer the project and keep track of the data produced by individual users and devices. The emphasis here is that in this case study the smartphone technology did not save on labour for either the researchers or the participants. Smartphones are not stand alone pieces of computing hardware. In fact, these devices only function as part of complex commercial, technical and legal networks comprising telecoms companies, hardware manufacturers, software platforms and government legislation. The use of smartphones as the basic unit of research means having to deal with the vagaries of the telecoms industry. One of the main problems we identified was the socio-technical assumption that each phone is owned by a single user and that the person setting up the device will also be the end user. This end user is required to enter lots of personal information in order to set up and initiate the device and the application. To our knowledge, there is currently no administrative system within participatory sensing that would allow for a centralised setup and ongoing management of a diverse collection of phones and apps by a project coordinator. This makes it very difficult to use smartphones for collective purposes. Rather than saving time or money, the use of smartphones in crowdsourcing projects involves large amounts of hidden labour and costs that are generally unacknowledged.

11.3.4 People Are Less Reliable Than technologies

The case study calls into question the assumption that technologies are invariably accurate. Despite having to use a highly inaccurate and untrustworthy technology, the case study demonstrated the role that participants can play in appropriating sensing for their own goals and agendas. This challenges the characterisation of people as MULEs, which elevates the technology, in this case the sensor, and excludes human decision-making. Unfortunately, in the literature, we still see a considerable degree of concern about the quality of participant observations and the associated dangers of *"wilful falsification, human deceipt[sic] and data manipulation"* (Srivastava et al. 1958, p. 189). Yet in environmental sensing projects, the participants who are involved are often living next to the source of the pollution and are directly affected by it. This means that they have acquired a breadth of expertise that makes them specific kinds of experts on that situation (Wynne 1992). In contrast, this highly specific expertise is often not available to the researchers, who are only looking at data. In the Heathrow case study, we observed that many of the participants were vastly more knowledgeable about the technical and legislative aspects of noise than our research team. We feel that it is dangerous to treat researchers and technologies as infallible, while participants are treated as unreliable sensors or MULEs. For participatory sensing to progress, it will have to acknowledge that there are different types of expertise that need to be brought together, not just a single one that can be embedded into technological sensors.

11.3.5 Motivation is a Universal Property

Why did people take part in the Heathrow project? The answer is that the project offered the participants a way in which to deal with local noise issues that were directly affecting them. In the pre-project survey, the participants wrote that they wanted to *"raise the bar for politicians thinking about the 3rd runway"*, and demonstrate the emotional impact of noise by bringing *"greater recognition of the impact of noise especially the frequency of interruption by planes"*. In this case study, motivation emerges not as internal, psychological or abstract, but as something that is involved with the external world; it is specific and contextual. For the participants, their motivation to take part in the sensing was intrinsically linked to the personal, communal and local relevance of noise. Thus in this case, the ability to sense aeroplane noise was critical since it functioned as a lynchpin in terms of political decisions about the future expansion of Heathrow airport, which would have a direct negative impact on their future quality of life. These clearly articulated and material motivations challenge the way in which crowdsourcing envisages motivation as abstract and universal. How would the practices of participatory sensing change if it actively engaged with people's real-world motivations rather than postulating essentialist drives?

11.3.6 Engagement Can Be Automated

As outlined earlier, very little has been written about recruitment for participatory sensing. The methods suggested for automated recruitment do not appear to offer viable solutions en masse. We suggest that this case study has demonstrated the viability of an issue-centred approach. By organising a series of workshops in the local area, we had many opportunities to communicate directly with the participants and crucially, the participants had opportunities to meet each other. This meant that the project did not only involve data collection; it created a collective effort of mapping noise. In addition, our proximity allowed fortuitous encounters to take place, which would not have been possible using an automated recruitment method. During one of our visits, we stopped at a local restaurant next to the workshop venue. After discussing the project with the owner, he decided to attend the workshop and he ended up participating and collecting data over a number of weeks. Our close contact with the participants also meant that we could support them by answering their questions about the software and replacing broken smartphones. We grew to understand how they were collecting data and what they were aiming to do with their collected data. This allowed us to create a number of custom noise visualisations, which focused specifically on the local impact of the airport. As a result of our issue-centred campaign, 80 people attended the face-to-face workshops as well as lots of public media and we managed to make the resulting data valuable for democratic decision-making on airport policy. Using this approach, 252 people (unique devices)

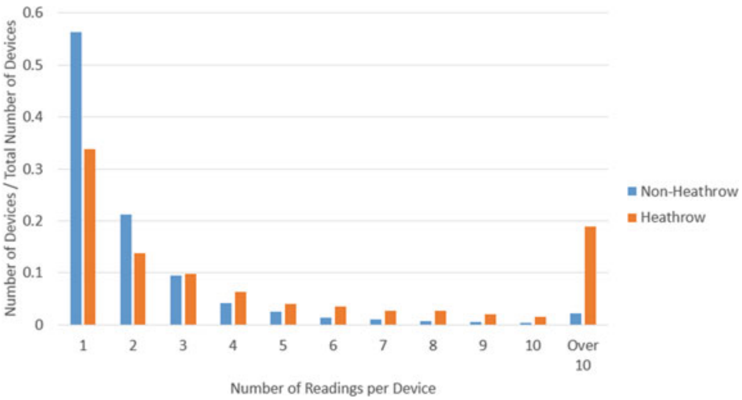

Fig. 11.4 Graph comparing the number of readings created per device in Heathrow vs. the rest of the world. 19 % of users in Heathrow took more than 10 readings while only 2 % in the rest of the world

took part in creating sound measurements around Heathrow and 6666 data points were generated in the area. We can compare the data from the focused sensing campaign with data from the rest of the world where people have downloaded the app independently, for their own purposes; see Fig. 11.4. The Heathrow data suggests that people on average took many measurements over an extended period of time, while in the rest of the world only 2 % have created more than ten data points. This suggests that using the app in an issue-centred context creates more in-depth and long term engagement, which makes sensing a valuable rather than an arbitrary process. These results suggest that an issue-centred approach to sensing can work for the benefit of local participants and local institutions as well as researchers. We argue that issue-centred approaches need to be seen as a viable model for participatory sensing projects.

11.4 Conclusions

This paper has described a number of assumptions of participatory sensing and the ways in which they create points of tension for the practice of sensing. We examined a case study that used the WideNoise app within the framework of an EU research project and described the technical and user testing required to understand the capabilities and constraints of the app. Based on the specific properties of the device, we outline an issue-centred approach to encase the app within a local issue of concern in order to recruit participants. Finally, the case study reflects on the assumptions of participatory sensing, the way they materialised within the case study and how we might be able to move beyond them.

Our key observation throughout this paper is the importance of the smartphone and its affordances, as well as the specifics of the software choices made in the design of the WideNoise app. The qualities of the device opened up and closed down many of the possible directions for a participatory sensing campaign. Our argument is not that technology fully determines sensing and that practitioners simply have to adjust to them. In a more nuanced way, we suggest that the technical and conceptual limitations of the hardware and application actively created possibilities as well as boundaries. We would like to describe our approach to participation and sensing as 'pragmatist' and in a tradition from Dewey (1927). This suggests a pragmatic approach to truth gained through pluralistic methods where facts and values are interlaced (Barnett and Bridge 2013; Hepple 2008) and brought together through experimental practices (Marres 2007). A pragmatist approach to participatory sensing means engaging with the real-world constraints of hardware, software and organisational requirements and trying to make the best of what one has within a real-world context. Thus, a pragmatist approach is honest in examining and communicating the limitations and trying to work with them to create a project. While in general it is better to be able to build custom applications and hardware for a specific social and issue context, however, this is not always possible. At the same time, pragmatism also means a lack of idealism about the human aspects of sensing in terms of people's supposed motivations. A pragmatic approach to participatory sensing is one of design based problem-solving. By using the word 'design', we propose that the device is not finished when a smartphone leaves the assembly line, or when a software developer has submitted the final update to the app store. Design carries on into the setting up of the sensing campaign. In our role as participation practitioners in this case study, we were redesigning the implementation of the WideNoise application. Furthermore, the users themselves were carrying out a type of design work in the way in which they created their own protocols of when and how to take measurements. If we adopt this expanded notion of design, then participatory sensing becomes much more nuanced in terms of the roles that researchers, participants, technologies and issues play. We would like to propose that in participatory sensing, humans and technology come together around issues of concern to form sensing assemblages. This idea of an assemblage, meaning literally a collection of things, describes this movement of gathering together that occurs within sensing. This idea of a gathering is a challenge to the assumptions of participatory sensing, which usually treats technologies and participants as entirely separate. By starting to draw this assemblage around an issue at the centre of our approach, we are in fact reframing problems such as motivation and recruitment as starting points and not merely something to be added to a technology. If participatory sensing aims to be truly participatory, then it will have to fundamentally rethink the design and development of its software and hardware platforms. Sensing assemblages need to be designed to support specific use-cases. Academic research processes need to be flexible enough to pragmatically adapt to the specific contexts in which the device is used and should be able to incorporate feedback and suggestions from participants in an iterative design process. Engaging with issues and working with participants needs to become part of the core design of creating sensing assemblages. Unless participatory sensing addresses the assumptions that become embedded into the design of its software, hardware and telecoms ecology, it will not be able to achieve its full potential. Participatory sensing can elect to construct the environment as a flat cartesian surface of data points without dynamics and life, or it can actively engage with the range of entities that are producing vibration or are at the receiving end of vibration. Using an issue-centred and pragmatic approach gives sensing an expanded context in which it can progress beyond recruiting data drones, towards engaging with the mechanisms and dynamics that cause environmental pollution. In this way we can build a future of participatory sensing that allows humans and machines to equitably co-sense the environment together.

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Chapter 12
Large Scale Engagement Through Web-Gaming and Social Computations

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12.1 Introduction

Technology plays a fundamental role in connecting people and circulating information, and affects more and more the way humans interact with each other. The number of users surfing the Web exceeded two billion in 2012 and an unprecedented

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huge amount of information is exchanged by people everyday through posts and comments on-line, tweets or emails, or phone calls as a natural aptitude of humans to share news, thoughts, feelings or experiences. The Web is thus entangling in an unpredictable way cognitive, social and technological elements, giving rise in this way to the largest interconnected techno-social system ever. Social networking tools allow effective data and opinion collection and real-time information sharing processes. The possibility to access the digital fingerprints of individuals is opening tremendous avenues for an unprecedented monitoring at a "microscopic level" of collective phenomena involving human beings. We are thus moving very fast towards a sort of tomography of our societies, with a key contribution of people acting as data gathering "sensors" and with a level of fine-graining that only 2 or 3 years ago would have been considered science fiction (see Chapter by V. Kostakos et al. in this volume for an overview on Human Sensors). All this has deep implications for the understanding of the dynamics and evolution of our complex societies as well as for our ability to start making predictions and face the societal challenges of our era. Social Science disciplines, traditionally depending on the recruitment of test subjects to perform experiments, are for the first time experiencing the possibility to gather significant data in an effective and capillary way, opening in this way the season of a computational social science (Lazer et al. 2009).

In this context, the use of the Web for research purposes is changing the way research activities are conducted and how data are generated and gathered in many scientific fields. Despite the prediction, cast in 2009, that the new social platforms appearing on the Web might have become a very interesting laboratory for social sciences in general (Lazer et al. 2009), the research based on the on-line participation of people still lies in its infancy and methodological and procedural obstacles have to be faced in order to make it a reliable tool of investigation. Two paradigmatic examples are *Planet Hunters*[1] (Fischer et al. 2012), a game in which participants can help in identifying new extra-solar planets using NASA data of star brightness and *Galaxy Zoo*[2] (Schawinski et al. 2010), in which players are asked to classify astronomic objects of galactic type, by browsing a catalogue of telescopic images. The above mentioned projects have in common the involvement of individual volunteers or networks of volunteers, many of whom may have non specific scientific training, to perform or manage research related tasks in scientific projects. In this sense these are two examples of *citizen science* (Arnstein 1969; Goodchild 2007; Paulos et al. 2009), i.e., a long-standing series of programs traditionally employing volunteer monitoring for natural resource management (see Chapter by M. Hacklay in this volume for an historical development of Citizen Science).

Citizen science projects are becoming increasingly focused on scientific research (Cooper et al. 2010; Nosek et al. 2002; Salganik and Watts 2009) and amazing results have already been obtained. For example, the 3D structure of viral

[1] http://www.planethunters.org.

[2] http://www.galaxyzoo.org.

enzymes that challenged scientists for years has been discovered thanks to the efforts of Foldit[3] players (Khatib et. al 2011), new candidate planets identified by Planet Hunters' participants managed to survive data verification tests (Fischer et al. 2012), and brand new astronomical objects were discovered by Galaxy Zoo's users (Schawinski et al. 2010). These examples show how social computation processes hold tremendous potential to solve a variety of problems in novel and interesting ways, and how amateur players are able to solve research problems in an effective way, competing with their professional researchers counterparts. Human ability to easily solve tasks that are difficult to solve by machines has been largely used for instance in labeling images, through the collaborative *ESP Game* (von Ahn and Dabbish 2004), or in language automatic translators, through the interactive learning platform *Duolingo*.[4] In these last two examples, the idea of linking playful activities with learning processes has led to the paradigm of Games With a Purpose (GWAP) (von Ahn 2006), i.e. a way of engaging people in games that can extract valuable information or work as a side effect of the game or the learning dynamics (Bowser et al. 2015; Deterding et al. 2011). The playful rearranging of experiments, together with their appealing graphic interfaces, is shown to be a fundamental ingredient for web-based experiments design, boosting user participation and data reliability (Gravino et al. 2011; Iacovides et al. 2014; Prestopnik et al. 2014), with many Citizen Science projects of success already embedding such ludic aspects in their web-pages (Eveleigh et al. 2013; Prestopnik and Crowston 2012).

This idea of *crowdsourcing*, a term coined in 2006 (Howe 2006), is also at the heart of on-line labour markets such as Amazon Mechanical Turk (AMT), where a job is distributed by employers in small sub-tasks that on-line workers can perform in return of proportionally small monetary payoffs. Interestingly, despite its mercenary aspect, AMT has proven to be useful for scientific purposes (Chilton et al. 2009; Mason and Watts 2009; Paolacci et al. 2010), by leveraging on its ease in recruiting a potentially large number of experimental subjects. This early experience with crowdsourced experiments has led to the recognition that Web experiments can be successfully used to study human collective behaviour and cognition, and can provide elements of validation of experimental practices in the Web (Suri and Watts 2011). From a scientific point of view, the price to pay to set up a Web-experiment is to renounce the full control on the way participants are recruited and the control on the environmental context in which tasks are executed.

The tenets of social computation are being increasingly exploited, but its use in the scientific community still lacks systematization. The realization of a single project often requires substantial effort and web-based experiments are still far from being standard research tools. The lack of tools that can greatly simplify and standardize the design of Web games and experiments is a major bottleneck in the exploitation of such new research opportunities. For example, despite its versatility,

[3] http://fold.it.

[4] http://duolingo.com.

AMT has not been conceived as an experimental platform, lacking dedicated infrastructures for the design of experiments, while offering some visual tools to develop simple interfaces. Experimentalists are left with the task of designing their own software solutions to manage interactions among participants and to build effective interfaces. Moreover, individual solutions to such problems often remain isolated with little or no cumulative growth of tools and solutions. Hence the need of a versatile platform to implement web-based experiments or games with a very small coding effort. The word "game" is here intended as a real time interaction protocol among few players implementing a specific task, as well as a synonym of experiment on interactive behavior. By providing the scientific community with a general purpose platform for social-computation and web-gaming, one can gather otherwise separate efforts to use Web resources for scientific purposes and provide the community with a tool to design experiments on the Web, from simple polls to more complex multiplayer games, bypassing much of the "hard work", e.g. hosting, user registry handling and user pairing/grouping, communication protocols, exceptions handling, etc.

The aim of this chapter is to describe the scheme of such a platform and to provide the essential ingredients that would allow researchers to create, submit and maintain their own experiments with ease. By following the above prescriptions, a fully operational general purpose platform to carry on experiments in the form of web-games was developed within the EveryAware project, i.e., the XTribe[5] platform, to which we shall refer explicitly in the following sections.

12.2 Main Features of a Multi-Player On-Line Experiment

The GWAP applications cited above show a vast variety of features and a very heterogeneous set of targets. But even these varied experiences have elements in common, beside the general idea of leveraging the force of the crowd. In order to introduce the necessary steps to build a GWAP, in this section we shall analyze the structural and technical components of a generic GWAP, from an abstract point of view without going into detailed technicalities. As a guide we shall consider here the structure of the ESP Game, one of the most successful GWAPs in terms of participation and results (von Ahn and Dabbish 2004).

In the ESP game, two players are asked to tag the same image, trying to match their tags. They will input as many tags as they want until one tag is in common to both; then they collect points as reward and move to the next image. Within a time limit of 2.5 min, the players have to agree on as many images as possible, to increase their score. The goal of the game from the experimenter perspective is to obtain realistic valuable tags for on-line images, to be used by search engines. Please note how the reward of the ESP game is constructed so that players validate their

[5] http://www.xtribe.eu.

suggested tags in a self-consistent automatic way and is further meant to discourage random tagging. We shall consider this game as a prototype that will make the analysis of the typical game components more clear.

At one extreme of our abstract structure lies the *developer*, i.e. a researcher willing to create a web experiment. At the other end lies the ensemble of *users* who will play the game. Depending on the experiment, this can be a wide community with common interests or a selected set of participants filtered by age, gender, language, or even geographical location. In the case of ESP, the participants do not know each other and have in common the only intent of entertaining themselves by labeling images. Developer and users are just the two ends of a complex structure and in the following subsections we shall describe what lies in the middle and permits the execution of the game.

12.2.1 The Interface: Interacting with the User

In the GWAP experiments there is a flow of information that, in most cases, starts from the user, e.g. in response to a given question ("how will the other player tag this picture?", in the ESP Game case). Therefore, the application will need a user interface allowing players to insert their answers. The interface should be designed by researchers with the goal of optimizing users' experience, ensuring an easy and enjoyable interaction. The user has to invest her time in paying attention to the application and the entertainment itself offered by the interface can be a reward for the user interaction. Moreover, to our opinion, a successful interface design will not only persuade the user to spend her time on the application but will also stimulate her to invite other people. A well designed interface should also help her in voluntary recruiting acquaintances, e.g. by leveraging on social networks features, such as tweets about the results, sharing of the results in Facebook, etc, always respecting the individual privacy and chosen with explicit consent (for an overview of privacy issues please refer to Chapter by M. Riahi et al. in this volume). Even if the fanciness of the interface is crucial, the designer has always to keep in mind the biases introduced by the interface. Each kind of interaction introduces biases, even the simple fact that users are interacting through a computer. As we said, the reliability of the information gathered is a fundamental point. Thus, the impact of each bias introduced has to be carefully considered in order to find a good compromise between the reliability of results and the user experience.

12.2.2 The Server Side Logic and Storage

Once the information has been gathered by the interface, in order to give feedback to users or results to the developer, it is very likely that some elaborations will be needed. So the application will need a logic elaboration part. In the ESP case, the logic component receives the tags from each of the two players, compares them and when a match is found, feeds the interface with a new image to be labeled. When the time is over, this component computes a score and sends it to both players. While the interface runs on the browser, i.e. on the user computer, the information processing should happen server side, in order to guarantee reliability and security (reducing the risk of failures, cheating and hacking). Moreover, the game logic may require complex computation involving data that the researcher cannot or does not want to make available to the user browser. Beside this, there is also a matter of control: the logic part has to be directly managed by the developer, the other end of our scheme. Hence, it should run on a machine under the developer control where all data generated by the experiment can be properly stored for further research and analysis. The logic part will also provide content for the application (e.g., pictures in the ESP Game). In other words, the logic part will take care of filling the interface with input and feedback, as well as of gathering results.

12.2.3 The Rest: Technical But Necessary Issues

The interface and the logic are the nearest neighbor of the user and of the developer, respectively. These two parts are the core of the application, the "unique" parts designed by researchers precisely on the project target. But the application itself is still far from being complete. There are in fact, at least three missing fundamental parts:

1. **A communication protocol between the two parts:**
   The communication between the interface and the logic is potentially difficult to implement. If we consider the simple case of a client initiating the communication by sending a message to a server, the solution is quite easy to implement (e.g., with a HTTP request). But in case of more complex communication structures, such as bidirectional asynchronous client-server communication or, in multi-player games, client-client communication, the implementation can be quite a difficult task requiring more sophisticated technologies (e.g., web-sockets).
2. **A user handling system:**
   When dealing with users, a certain set of functionalities is likely to be useful such as user registration handling and profile management. At a basic level, it is a matter of security and reliability, because registration can provide a first filter against automated surfers (bots). Beside this, many experiments require a certain level of profiling of the users, to differentiate or group them depending on the gender, age, language, etc. On the other side, users may enjoy to see the result of their efforts, in the form of scores, ranks, etc. So they would prefer their "player" identity to be recorded by the game. Obviously, linked to this, there are also privacy issues: the developer has to guarantee to the user that her personal data will not be disclosed.

3. **An instance processing mechanism:**
   Once the interface has been prepared, the logic is running, they are communicating and the user is registered (if required), an instance of the game still has to be created, in order to allow the user to join the experiment. By instance we mean the single execution of the experiment task involving one or more users. This management is relatively easy for single player games, but it becomes non-trivial in case of multi-player games. A "waiting room" has to be implemented, in order to make the users wait for others to join.

These three parts have two things in common. They are needed (if not all necessary they are at least all very useful) in almost every kind of web-application and are not particularly influenced by the specific experiment or game. Hence, since these three parts are almost unrelated to the experiment, they are the most technical and dull to implement. That is why a framework or, even better, a platform that can take care of these functionalities automatically would make it easier to create web experiments. This is where platforms like XTribe come in, to provide the technical "middleware" (i.e. Sect. 12.2.3) and allow the author of the game to focus on the game-specific interface and logic (i.e. Sects. 12.2.1 and 12.2.2). But the benefits of such platforms are not limited to these.

12.3 An Existing Platform in Detail

Again, we refer to the already existing XTribe platform developed by the EveryAware project to go deeper into the detailed description of its functionalities. The XTribe platform has been designed with a modular structure so that most of the complexity associated to running an experiment is hidden into a Main Server (called Experimental Tribe Server or *ET Server* for short). In this way most of the coding difficulties related to the realization of a dynamic web application are already taken care by the ET Server and the realization of an experiment should be as easy as constructing a web-page with the main utilities for it. There are different kinds of users of the platform: the system administrator who runs the whole ET Server and provides all the necessary API's for it; the experimentalists who run individual experiments; and the players who participate in one or more individual games.

On the XTribe platform each user/player interacts with one or more of the available experiments/games. Each game is conceived by the game developers/researchers who monitor the evolution through their local machines. Games have two components: the user interface (UI) and the logic/game manager (GM). The interface is what is visible to players, and will interact with them. The GM is represented by those functional parts that process the action of the players in order to implement coordination and specific game logics. *These two components (the UI and GM) have to be developed by the researchers*, since they are highly dependent on the game itself. XTribe mediates the communication between the two and hosts the game interface. The GM part of the game is hosted by the researchers

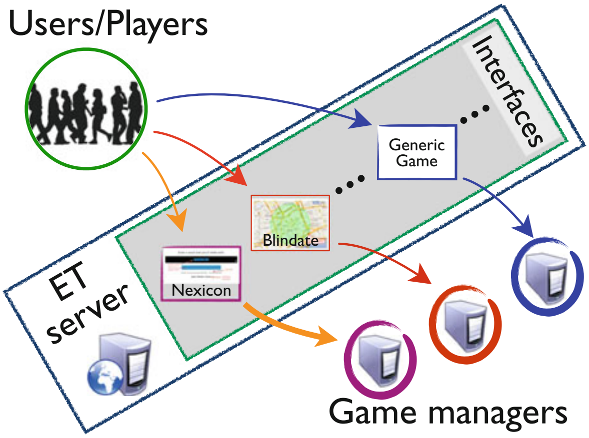

Fig. 12.1 A graphical representation of the system and its interactions

on their own server. In this way they can directly collect the data in real time and have full control over the experiment progression. It is important to remark that XTribe does not store the data coming from the hosted experiments. All scientific data collected during an experiment can be conveniently stored by the GM, so that only the researcher who developed and published the experiment benefits of the outcome of his/her work. Beside this, gathering data directly grants the opportunity to analyse them as soon as they enter the system in real time.

The XTribe platform also offers a page for the description of the game rules, compiled by the researcher, from which players can access and play the game. Additionally, it handles player/user management (registration, authentication and profiling) and manages the actual instances of each experiment (creation, user grouping, error handling, feedback to users and managers, etc.). A graphical representation of the platform is depicted in Fig. 12.1.

12.3.1 User Management and Community

Since experiments are created for research purposes, the researchers are interested in many types of statistics related to players. Beside this, they may also be interested in filtering players for specific purposes, e.g., according to their age, gender, language, geographical location, etc. To this aim, XTribe handles a user registry in which players will be allowed to register, if required, and play while the system maintains all the information about them, such as scores, ranks, game settings, leaderboards, etc., together with profile information. If needed, this information can be sent to the GM, i.e., to the experimentalist. Furthermore, based on this information, when properly configured, the system will grant the access to the game only to certain profiles. Being in charge of the handling of the user registry, the system would also spare the researcher from dealing with privacy and security issues since all data will be properly anonymized and, possibly, encrypted. However, by default, it is still possible for unregistered users to access the games. Filters are applied only if set by the researcher.

12.3.2 Underlying Module Communication

The communication between the UI and the GM is mediated by the ET Server through a message based protocol. The general functionality of a game can be summarized with the following flow:

- Once the players have accessed the game, the system will create an instance of the game. There may be given rules for the game to start. A basic rule is the number of players. There may also be different constraints, e.g., pairing players with similar scores or players playing from different geographical locations. As soon as there is a sufficient number of players satisfying the grouping constraints, an instance of the game starts.
- The interface will transmit the actions of the players to the GM, but all messages will pass through the system, which will group them by match instance number after having anonymized them.
- The GM will then receive the data, will elaborate them and will send the results of the elaboration back to the system, which in turn will transmit them to the UI of the various players. Obviously, the GM will also save the data of interest locally (as it runs on the researcher's machine).

It is important to remark that the GM can send messages to the UI either as a response of a message coming from a player (responding to that player, to the others or broadcasting to all of them) or by initiating the connection autonomously (e.g., after a given time). The platform will also handle errors and exceptions. For instance, if one of the players disconnects unexpectedly, the system will detect and notify it to the remaining players and will send a message to the GM. Since there is no direct communication between GM and interface, the GM will experience no trouble at all.

In Fig. 12.2 we depicted the communication flow of a two player game: a first player joins the experiment and waits for the second one to come. When both players are there an instance is created and the player's browsers are instructed to load the game UI. When loading is completed the UI notifies XTribe which in turn notifies the GM. Up to this point everything is automatic. The GM will probably send custom data back to the players to let the game start. During the game custom data are exchanged between UI and GM, until the game is over and the instance is closed.

All these features, especially the user registry and the instance handling, usually require a lot of coding, quantified in time and money, to be realized. With a platform like XTribe, these can be realized with a straightforward procedure. After the

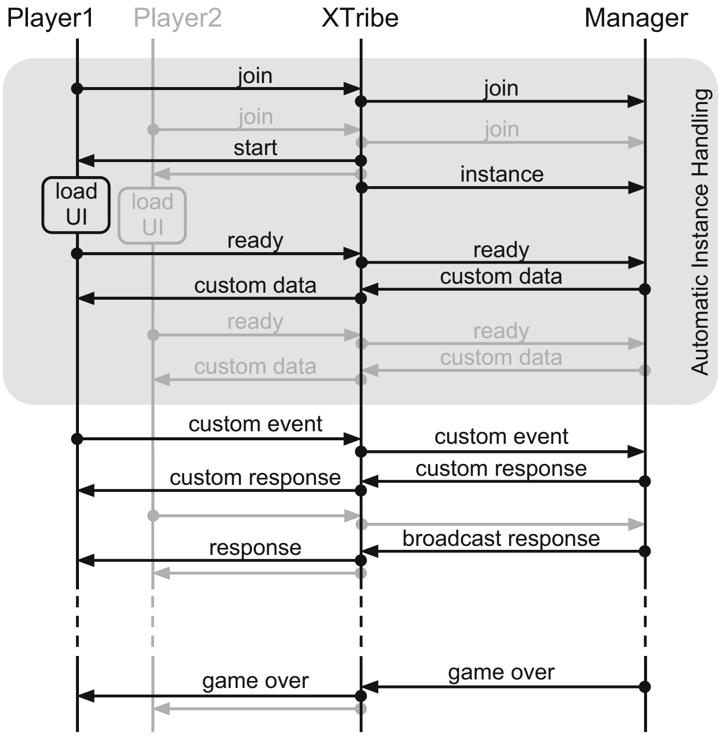

Fig. 12.2 Sketch of the communication flow of a two-player game on XTribe

configuration, the system will automatically take care of all. What researchers have to do is to write down the code of the UI and of the GM only.

The UI may be structured as a web page with plenty of freedom in using HTML, CSS, Flash, etc., while the interaction between the interface and the system can be achieved by means of ET Server API's, which can be developed in any programming language (we used Javascript functions in XTribe). With this simple set of functions the interface will interact with the platform and, through it, with the GM. Basically, the GM has to work as a simple HTTP server hosted on the researcher's machine. The communication with the system may take place simply through the HTTP protocol and all messages could be coded, e.g., in JSON format. The GM receives the message as a POST string variable and sends back one or more messages with a JSON string in the response body. Besides a restricted set of system messages, the researcher is given full freedom to decide custom messages for the internal game protocol.

12.3.3 Social Network Integration

Since the strength of on-line games comes from large participation, their success may be boosted by their integration with the most popular on-line social network application, *Facebook*. Through Facebook the recruiting of new users is easier, since the games offered by the platform can spread through the network faster by word of mouth. The integration may consist in the possibility to view the platform interface within the Facebook website and play games as Facebook games. Additionally, it provides seamless user registration, integrating the Facebook user information with the platform user registry. Hence, players have a better user experience connecting to the platform without having to insert their personal data again, while researchers can collect more demographic information about the players of their games. Of course, the registration by means of FaceBook would not be the only way of registering, since there can be users who do not agree to divulge their private data stared in FaceBook, and other login procedures have to be implemented. Regular posts on user activity on the platform are published on user walls, and in this way additional players can be attracted to the system. Researchers wishing to build new games take advantage of this integration without any additional effort from their side.

Another interesting possibility is to use the platform in conjunction with the Amazon Mechanical Turk (AMT) platform in order to exploit its ability to recruit users with a modest monetary investment. AMT can be used to enhance participation and possibly in the initial phase of an experiment, to provide the necessary pool of data to bootstrap with. The simplest way two integrate both platforms is to simply releasing an AMT payment code at the end of every single match or experiment. This code can contain information on the kind and amount of reward to deliver, in accordance with the results achieved by players.

12.4 A Sample Experiment Implemented in the EveryAware Project

In the context of the EveryAware project the XTribe platform hosted two experiments dealing with users opinions and perception evolution. The gamified approach allowed a wider and less expensive data gathering, in particular during the final EveryAware case study on Air Pollution (see Chapter by P. Gravino et al. in this volume). In the following we will describe our experience in delivering a web-based game for scientific purposes by analyzing a particular game hosted in XTribe. The chosen game is "Joe's City Race", which is particularly interesting since it was played by two different class of players with supposedly miscellaneous motivations, as it will be clear in the following.

12.4.1 Joe's CityRace

CityRace is an experiment that aims to analyze the response of drivers to traffic information, in an age when an increased interest in enhancing social activities, with the use of new technology, has led to the development of multiple applications displaying real time information for drivers. However, the effect of such information on driving behavior remains unstudied. Participants have to draw a best route between two points on a map, generating in this way important data describing user choices and testing whether traffic information is beneficial. The playful aspect of the experiment is implemented by adding a scoring system that rewards players according to how well they perform in identifying the shortest path, in terms of time of travel, with respect to the Google Direction engine. Street usage during the game generates a synthetic traffic dataset that, in certain cases, can identify locations in a city where the network structure prevents users from avoiding traffic congestions. For this analysis, we discuss two user groups, corresponding to two experimental settings with different stress levels and goals, which show differences in performance. One group was composed mostly by players taking part in a special event organized in a bookstore in Rome, while the other was set up by recruiting players in the virtual labor market of Amazon Mechanical Turk. CityRace constitutes a virtual social laboratory, where different aspects of human behavior in response to available traffic data can be analyzed. Although several tools for displaying traffic information exist (e.g., Google Maps, Autostrade per l'Italia, Waze), their effect on driver behavior has not been at all analyzed. Such a study may uncover important aspects of how much information a user needs and in what context the information is useful. We propose to use the GWAP approach for this, and describe here the results obtained after the first test cases. The XTribe platform has proven to be very effective through its flexibility which has facilitated the implementation of the web game.

Two different groups of users were involved in CityRace. The first group was mainly composed of participants to a demonstrative event organized in a bookstore in Rome, together with a few other players who joined the experiment on their own by surfing the web or through Facebook advertising by our group members. The second group was composed of workers recruited from the Amazon Mechanical Turk (AMT) virtual labor market. These two groups took part in the experiment with different goals. It is likely that the first group joined the experiment with entertaining purposes, while the second was primarily interested in maximizing their monetary income. Despite their strong bias towards profit, AMT users revealed to be sufficiently reliable for scientific purposes and produced meaningful data connected to simple experiments (Paolacci et al. 2010). Our case is interesting because, in order to play CityRace correctly, a significant cognitive effort is required, so that the question of AMT user reliability for such demanding tasks is not yet assessed.

Although CityRace has been considered here as a test case for the XTribe platform, it is connected to interesting open questions. One such question is whether displaying local traffic information changes user behavior, and under which conditions. Also, how much information is needed to trigger a change in behavior?

In real life, how much information on the state of immediate neighborhood is required for the citizen to be able to optimize the route? For this, the platform displays different amounts of traffic information in each game, which will allow for an analysis in this direction to be performed. This is useful both from the social science point of view and for optimizing future applications that offer visualization of routing and traffic information.

Furthermore, a virtual traffic dataset is generated, based on the routes selected by users. This, analyzed in comparison to the real data, can enable identification of traffic features related to street network topology. Also, the overall response to the real traffic displayed can be studied, showing whether avoidance of traffic can create jams in other locations of the city.

12.4.2 Game Details

In CityRace the player is shown two points, A and B, and has to choose a driving route between the two. There is also a Duo version which allows two players to compete each other in real time as a multi-player game, however this latter version was not fully deployed and analyzed.

In order to enable the study of the effect of traffic, the game consists of two stages. In the first stage, the map is shown without any traffic information, and users have to draw the route between A and B by selecting successive points on the map (within an active green area with the side of about 600 m). Once the route is completed, the second phase begins. The player has to draw a route again between the same two points, but with traffic information displayed on the map, color coded for each street segment (red—busy to green—light traffic). The user can select the same route as in phase 1, or change the strategy, as an effect of having traffic information available. Figure 12.3 shows the user interface of the game, with its different features.

Since we are also interested in how the amount of information affects behavior, traffic information can have different sizes (i.e., from a small to a large square area around the current location of the player). The possible widths of the traffic information area are: 400, 900 and 1300 m. Also, the points A and B are generated randomly at different distances: approximately 550, 800, 1100 m, to analyze whether the length of the route also affects user behavior.

At the end of the game, a score is computed for each phase. This takes into account the driving distances and times, using the traffic information available. Distance and time are compared with the best Google route, from the Google Direction engine. A high score (over 100) indicates that the user has over-performed Google. The final score of the game is the average over the two phases.

The City Race game has been available on-line since May 2012, for any player to join. To promote participation, a special event organized for the entire XTribe platform took place in June 2012, in Rome, Italy. Moreover, we have used AMT to obtain additional data. While other users played the game without any reward, AMT users have been remunerated with an amount of money related to their score.

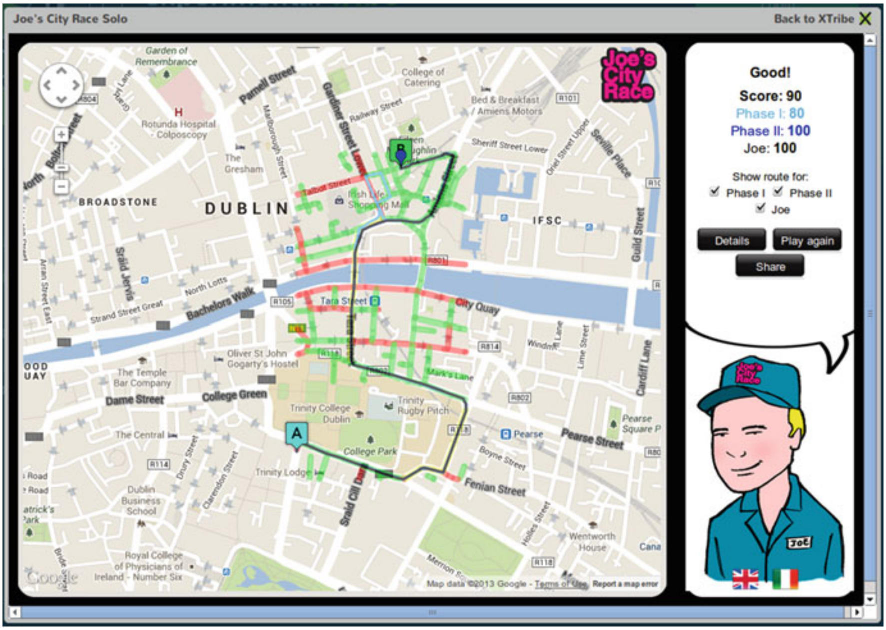

Fig. 12.3 City Race game: map, traffic, user route and score. The game was played 1310 times (as of 26 June 2013), out of which 708 by AMT and 602 by unpaid users directly on the XTribe platform

Specifically, the incentives were as follows: players received a base pay of 0.15 US$ irrespective of their final performance provided that they would terminate the game session successfully, and collect the AMT payment code; a bonus of 0.10 US$ was assigned for defeating the Google Directions engine and a further bonus of 0.05 US$ was given for improving the score in phase 2; moreover, a linearly growing bonus ranging from zero to 0.15 US$ was added for scores from 70 up to 150 (for scores over 150, the bonus was 0.15 US$). In total, the reward could range from 0.15 US$ to a maximum of 0.45 US$, which is quite high if compared to AMT standards. The test cases presented above resulted in 1310 games played (as of 26 June 26 2013), out of which 708 by AMT and 602 by unpaid users. In the following we will discuss the results obtained by these two groups.

First, we are interested in the scores obtained by users, as these show the overall level of performance. Figure 12.4 shows the distribution of scores (scores from phase 1 and phase 2 considered together) for the two groups of users (AMT and unpaid). Specifically, each point shows the fraction of routes drawn by users (vertical axis), which score more than a given value (horizontal axis). This shows that in general most of the routes drawn by players score under 100, meaning that they are not better than the route indicated by the Google Directions engine. However, there are players who do achieve better performance (25 % of the routes chosen by AMT users scored more than 100 points, while the routes chosen by non

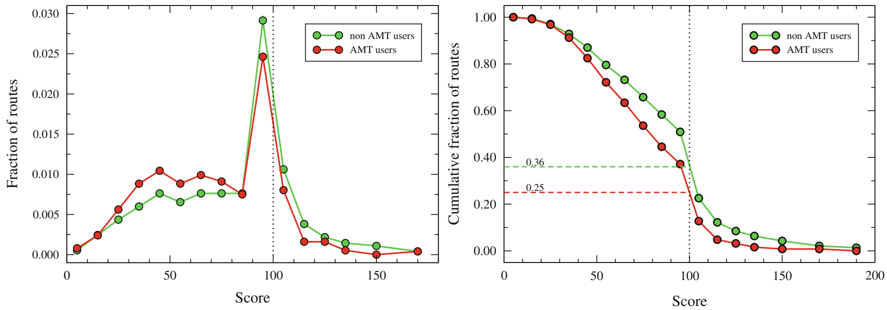

Fig. 12.4 *Left panel*: Fraction of routes with given score for AMT and non AMT users. The Kolmogorov-Smirnov test rejects the hypothesis that the two samples are originated by the same statistical distribution. *Right panel*: Cumulative fraction of routes compared for AMT and non AMT users. Each *point* corresponds to the fraction of routes that have a score larger than the values given by the *horizontal axis*. Note how non AMT users perform better than AMT users since the *green curve* lies always above the *red* one. In particular, 25 % of AMT users and 36 % of non-AMT users scored more than 100 points, which is the average score of the Google Directions engine

AMT users were sensibly better since 36 % of them scored more than 100 points). Also, AMT users score less than other users, indicating that their routes are less optimal (see Fig. 12.4). A Kolmogorov-Smirnov test rejects the hypothesis that the two samples are originated by the same statistical distribution (p-value $\ll 10^{-6}$).

This might be on one side due to individual characteristics of the players. Most AMT players are from the USA (ca. 47 %) or India (ca. 34 %), so are less familiar with the European cities included in the game, and with European street networks which are significantly different from e.g., the grid-based American ones. However, on the other side, the AMT users are also playing under different conditions, with more pressure for time, which may indicate that drivers trying to get to a destination faster actually end up using a suboptimal route, even when additional information is available.

To recap, based on the experimental setting, we have divided the players into two groups, one without time constraints (low stress) and the other with strong time constraints (high pressure) to complete their task. Results have shown that users under pressure (AMT users) obtain lower scores in general, and seem to use traffic information less than the non-AMT users. However, larger amount of such information appeared to be beneficial in choosing a route. Differences between the two sets of users also indicate that *paying for citizen science projects might not give the same results as other incentives*, especially when the tasks to be accomplished bear a substantial cognitive effort. Paid users will tend to maximize their revenue to the detriment of the experiment quality.

Additionally, we have shown how user activity may suggest problematic areas in the transportation network in a city. We stress that CityRace was intended here as a test case for the XTribe platform to prove its ability to involve players coming from different settings (unpaid and paid) and to test its response to massive user participation. The use of the XTribe platform has considerably facilitated the construction of CityRace, which was developed without the burden of implementing the code to manage user registration and the creation of game instances. As soon as a community of players will form around XTribe, the data collected will be refined by filtering users according to their degree of knowledge of the urban environment they will play in CityRace. In this respect, we are aware that many of the players never lived in the cities proposed in the game so that their strategy was based on the visual map only. The CityRace game will remain active on-line and recruiting activities will continue in order to gather more data and refine this analysis.

12.5 Conclusions

In the area of interest of GWAPs it is useful to have access to a general purpose platform that handles all the aspects of the realization of web experiments that do not concern directly the game itself. In this way, researchers can focus only on the core of the experiment, leaving the rest to the system. The XTribe platform developed in the EveryAware project is a valuable example of such a platform.

The XTribe platform is already running and has proved its usefulness with several games already implemented by different researchers. The already existing games refer to studies in language and opinion dynamics, where the human component plays a crucial role, and are designed as web based social experiments. They show the versatility of the platform and its ability to host experiments on a diverse range of topics, such as word association games, citizen mapping, responses of individuals to traffic information, expressing political opinions. These are prototype experiments thought to test both the ability of effectively recruiting participants and the scientific reliability of the data collected. Besides their immediate scientific interest, they are meant to open the way to the use of this on-line laboratory, also involving other potentially interested research groups.

An important concept is to allow researchers working in different fields, who lack computer science expertise, to create web-based experiments and games. In order to further facilitate this, the next step is to create a set of “default” GMs for games corresponding to the most standard types of web experiment, such as surveys or coordination games. For the time being, in XTribe, there is a default GM available that broadcasts to all the players the messages received from each one.

A platform like XTribe is expected to act as a reference point for interested users, giving a fundamental boost in facing a typical issue related to web experiments: the recruitment. It is quite difficult to gather a critical mass of “suitable” players, and this can be an easier task for an organized and collective platform than for single games. A first step towards facilitating recruitment was Facebook integration. In time, this process will become easier for new games. We think that, since the games are hosted on the platform and shown on its main page, other players already involved in other games will probably join, attracted by curiosity. We expect a community of players to gather around XTribe playing different games and also giving researchers feedback about their experiments. We also hope that researchers themselves will aggregate into communities, sharing advices and best experimental practices with each other. In the near future, the platform will made available classic tools for cooperation such as a forum, to discuss experimental procedures, and a repository for GM and UI, where willing researchers can make their own code free for download and reuse.

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Chapter 13
Participatory Air Quality Monitoring in Urban Environments: Reconciling Technological Challenges and Participation

Jan Theunis, Jan Peters, and Bart Elen

13.1 The Possible Roles of Participatory Air Quality Monitoring in Urban Environments

Whereas emissions of several air pollutants have significantly decreased in the EU and the US in the last decades, the effects of poor air quality are still strongly felt in urban areas (European Environment Agency 2013; U.S. Environmental Protection Agency 2012). In urban environments, exposure to traffic pollution may trigger health effects like cardiovascular diseases and airway inflammation. Understanding local variation in exposure to air pollution is of major importance when trying to assess the health effects of pollutants that are highly variable in time and space, as is the case for traffic-related air pollutants (Setton et al. 2011). Recently, mobile air quality measurements are used in several studies for exposure monitoring, for high resolution mapping of the spatial variability of air pollution and for the characterization of particulate air pollution in urban environments. However, to be representative a lot of data have to be collected in a cost-efficient way.

Participatory monitoring and citizen science are often mentioned as ways to collect large datasets that give useful additional information at a reasonable cost compared to classical data collection methods. There is a growing body of literature on participatory environmental monitoring (also called citizen sensing, citizen science or community-based monitoring) in general and urban sensing more specifically. Often the motivation for voluntary or participatory data collection is rather utilitarian and driven by scientific or policy data needs. Through the efforts of hundreds of volunteers data will be collected with a spatio-temporal granularity that cannot be achieved by regular monitoring campaigns. The challenge then is to

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recruit volunteers who are intrinsically motivated, or to set up incentive strategies to motivate people to participate. Successful examples exist in the field of biodiversity monitoring. Roy et al. (2012), Conrad and Hilchey (2011) and Catlin-Groves (2012) give extensive overviews of cases and lessons learnt in ecology and nature conservation.

Participatory monitoring or citizen science is also believed to raise the awareness and understanding of citizens (e.g. Snyder et al. 2013). Projects can be set up with that specific objective in mind. Citizen science is recognized in many studies as a way to include stakeholders and the general public in the planning and management of local ecosystems (Conrad and Hilchey 2011). Involving organized stakeholders and the general public in environmental assessment can also lead to better and common understanding and awareness of the issues at stake and of the local context, mobilisation of local knowledge, joined problem ownership, and co-creation of solutions. Policy makers, citizens and stakeholders could set up participatory monitoring schemes with the specific intention to create or stimulate dialogue and provide a better basis for decision making. As such, participatory monitoring can have an important role as a part of co-creation and transition processes towards healthier cities. A recent report from the European Commission on Environmental Citizen Science (Science Communication Unit, University of the West of England, Bristol 2013) states however that few studies on public participation in science and environmental education have rigorously assessed changes in attitude towards science and the environment, and in environmental behaviours, and concludes that it is difficult at this point in time to provide evidence for the influence of citizen science on environmental policy making.

When evaluating participatory monitoring approaches we thus have to distinguish clearly between two types of objectives:

1. the *scientific* objective which focuses on the factual results of the monitoring campaign;
2. the *social learning* objective which focuses on processes of creating shared knowledge and visions, awareness and behavioural change, co-creation and transition.

Both objectives cannot be entirely distinguished from each other, and there are clear co-benefits. Whereas participation of people in scientific research programs can be quite instrumental with possibly a beneficial overflow on people's knowledge, awareness and attitude towards the issues at stake, sound monitoring methods are crucial for both objectives.

13.2 Challenges for Participatory Air Quality Monitoring

Already in Burke et al. (2006) mentioned the theoretical potential of participatory sensing to investigate relationship between air quality and public health. In Snyder et al. (2013) US-EPA scientists give an overview of possible changes in air quality monitoring due to the materialization of lower-cost, easy-to-use, portable air pollution monitors (sensors) that provide high-time resolution data in near real-time. Participatory monitoring techniques could be used e.g. to improve the understanding of the relations between urban traffic, air quality and health.

Following successful examples of large scale collaborative efforts such as OpenStreetMap or Wikipedia, bottom-up Do-It-Yourself (DIY) monitoring approaches based on low-cost sensors and smartphone apps are appearing in domains such as noise, air quality or radiation monitoring. Often the idea of pervasive or ubiquitous sensing is put forward, relying on a multitude of sensors with which data are collected in an un-coordinated almost effortless way, and on intelligent data post processing and mining.

In Part 1 of this volume Theunis et al. deal extensively with the availability, cost and quality of environmental sensors and monitors. Although several projects, research groups or companies recently developed light-weight devices, integrating low-cost gas sensors, GPS and mobile phones, the authors conclude that for air quality monitoring—stationary or mobile—no sensors or monitoring devices are available at this point in time that would allow such pervasive effortless data collection either because of inherent quality issues or because of their cost. Proper use of available low-cost sensors still requires important multidisciplinary development efforts.

Air quality monitoring strategies further have to deal with a complex mixture of gases and particles that is highly variable in space and time. Figure 13.1 shows results of an extensive mobile air quality monitoring campaign in Antwerp to assess the exposure of cyclists to ultrafine particles (UFP) and black carbon (BC) (Peters et al. 2014). The same route was measured in repeated continuous measurement runs (up to 258 times) at different times of the day during 11 days with a resolution of 1 s. The measurements were aggregated to fixed points every 10 m using GPS data and a Gaussian weighing function. The hourly averages clearly illustrate the spatial variation and the intraday variation of these components at different locations. Single measurements (or mobile measurement runs) are subject to additional variability, e.g. due to specific events, such as a car passing by, and thus have very limited value in assessing air quality at a specific location.

Figure 13.2 shows the daily variation for black carbon during this measurement campaign. It is clear from these data that drawing general conclusions on air quality based on the measurements of just 1 day, or comparing results from two locations that were measured on different days doesn't make sense.

Different air pollutants also show different spatio-temporal patterns. Spatial variability is much higher for ultrafine particles or black carbon, that are directly related to fresh engine exhaust, than for PM_{10} which is for a large part the result of physico-chemical transformation processes (Peters et al. 2013). Differences in pollution patterns are even more pronounced when comparing e.g. ozone and NO_2 that even show antagonistic behavior, as freshly emitted NO from vehicles reacts with ozone to form NO_2. As a result, at days with overall high O_3 concentrations, O_3 concentrations tend to be lower in urban areas with a lot of traffic.

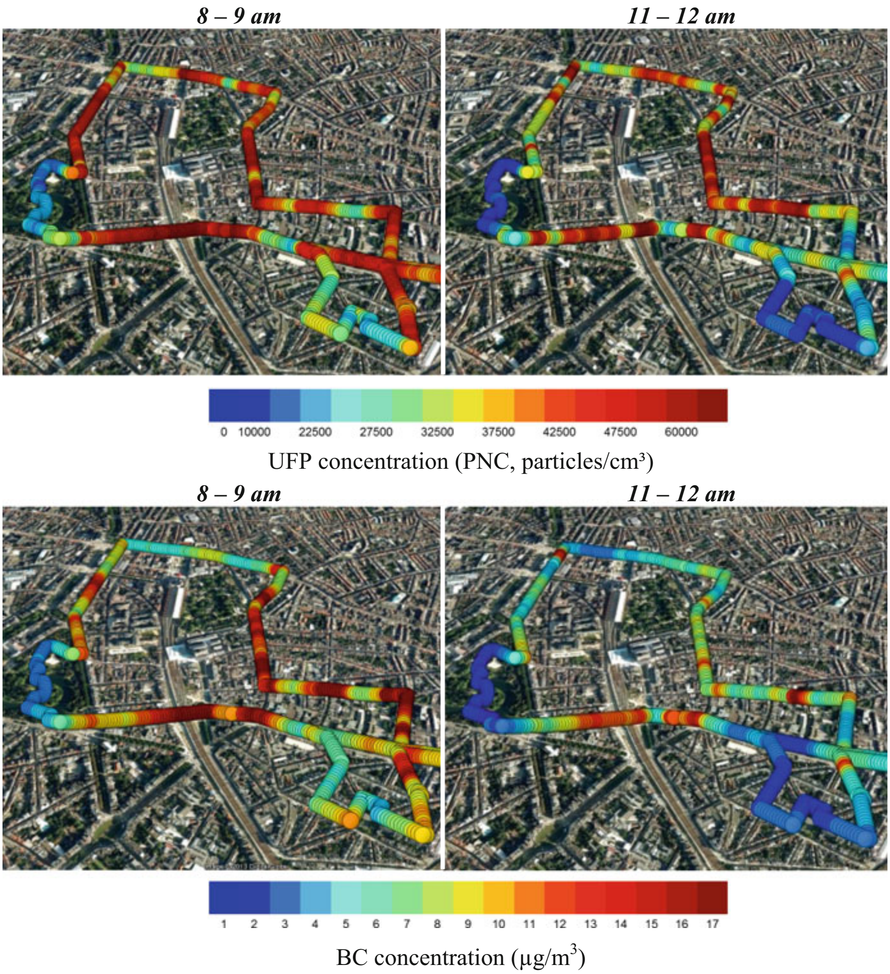

Fig. 13.1 Differences in air pollution at different hours of the day along a cycling route in urban environment. Displayed are hourly averages from 8 to 9 am (*left*) and from 11 to 12 am (*right*) at 10 m resolution of ultrafine particle number counts (PNC) (*on top*) and black carbon (BC) concentrations (*below*) (adapted from Peters et al. 2014)

Monitoring strategies thus have to set clear goals on which components will be monitored, over which area and which time frame. Selection of pollutants to be monitored depends on the issues at stake. Monitoring strategies further have to take into account the spatial and temporal variability of pollution. Finally, the results of monitoring campaigns have to be interpreted in the light of this complexity. All this requires a reasonable level of basic knowledge on air pollution. The role of expertise cannot be underestimated, in assessing the quality of sensing devices, in setting up a monitoring campaign, as well as in the interpretation of the results. Based on

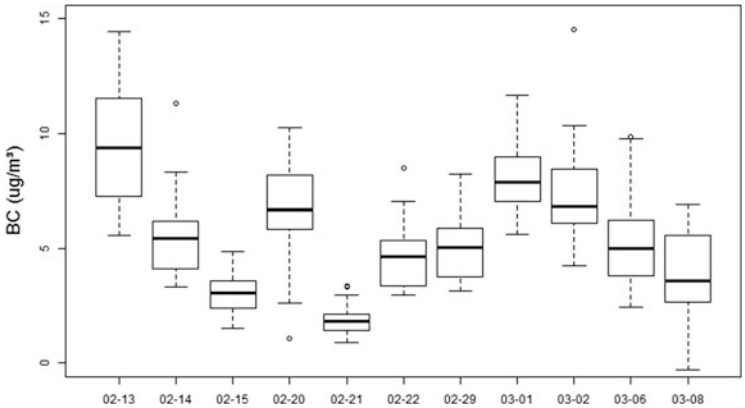

Fig. 13.2 Differences in air pollution for different days along a cycling route in urban environment. The boxplots show the black carbon (BC) concentrations aggregated at 10 m resolution (adapted from Peters et al. 2014)

a series of qualitative interviews with scientists who participated in the 'OPAL' portfolio of citizen science projects that has been running in England since 2007, Riesch and Potter (2014) stress the need for clear goals, careful design of projects and appropriate quality assurance methods. Because of its inherent complexity, this is undoubtedly the case for participatory air quality monitoring.

13.3 Framework and Guidelines for Participatory Air Quality Monitoring

The potential for participatory environmental monitoring crucially depends on three strongly interdependent factors: the availability, quality and cost of monitoring tools (sensors, apps, ...), sound data collection and data processing methods, and finally the participation of volunteers.

In the following paragraphs we will propose a pragmatic framework for participatory air quality monitoring that deals with these three aspects, and illustrate it with practical examples (Fig. 13.3). We will illustrate how participatory air quality monitoring can have an added value in the scientific process—in improving facts and knowledge, and how participatory monitoring campaigns (bottom-up approaches) can be conducted by lay people. Although we acknowledge the possible role of participatory monitoring in processes of awareness creation or decision making, we will not address these issues in detail. However, we do believe that the proposed framework is also applicable in these cases.

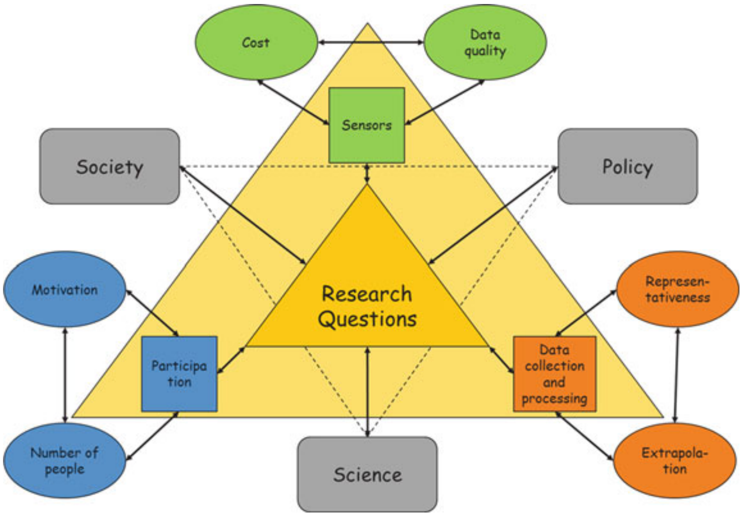

Fig. 13.3 Conceptual framework for participatory air quality monitoring

13.3.1 Defining Research Question and Monitoring Objectives

As with all monitoring exercise, the research questions are central to each participatory monitoring exercise. The research questions will determine which components will have to be monitored, over which area and which time frame. For a monitoring campaign to be effective research questions have to be made explicit and specific. Research questions can be defined by policy makers, scientists, stakeholders or the society at large (Fig. 13.3).

A lot of data and information on air quality is already available, some of it in the scientific community, some of it for the general public. The first step is thus to understand what is already known and available. Then research questions can be refined, and efforts can be focused on the possible added value of participatory monitoring campaigns, i.e. compared to official permanent monitoring networks. Spatio-temporal variability might be well covered for some pollutants by the official monitoring networks. E.g. the official monitoring networks will capture day-to-day and intraday variability of PM_{10} or O_3 quite well, and will be able to provide most answers regarding their spatial variability. The highest added value for participatory monitoring lies in monitoring those components that have a strong micro-level spatial variation, that are health-relevant and/or that are not monitored in official monitoring stations. Therefore, additional monitoring efforts in urban areas are more relevant for black carbon, ultrafine particles or NOx than for PM_{10}, $PM_{2.5}$ or ozone (see also Theunis et al. in Part 1 of this volume). We do acknowledge that Do-It-Yourself monitoring can also have an important didactic effect, even if it does not add much to the existing data or knowledge. However, also in those cases learning will be most efficient when these exercises are combined with discussions with experts. Otherwise the danger of misinterpreting data or re-inventing the wheel is real.

Defining clear research questions, and developing a sound monitoring strategy based on clear objectives, in a clear spatial and temporal framework, is the first step in a successful monitoring campaign. We can broadly distinguish three types of objectives: monitoring *specific events* or *locations*, systematic *mapping of areas* or *personal exposure assessment*.

One can be interested in the effects of *specific events* that are clearly confined in space and time, such as changes in air quality during road works. Events can also be recurrent, e.g. one can be interested in the occurrence of peak concentrations caused by trucks or buses passing by at a certain location. In this case both the magnitude of the peaks as well as the frequency at which they occur can be of interest. It is also possible that the focus is on one *specific location*, e.g. a school or a busy traffic intersection. In most of these cases a stationary monitoring approach will be most suited.

Several objectives can be pursued by systematically *mapping an area*: getting an overview of the air pollution in an area for verification of legal norms or health impact assessment, identifying pollution hot spots and relating them to specific sources, or comparing air pollution on different routes. Representativeness of the maps is a crucial issue, and should be in line with the research questions, e.g. average annual concentrations or average concentration in a holiday period, average pollutant concentration during peak hours or during off peak hours. In this case monitoring strategies can rely on stationary monitoring networks the density of which should be in line with the spatial variability of the pollutant at stake, or on repeated mobile measurements (Peters et al. 2013; Van den Bossche et al. 2015).

Finally, one can be mainly interested in the level of pollution people are personally exposed to during (part of) their daily activities. People can be interested in their individual exposure. But, one can also be interested in the personal exposure of subgroups of people, such as children or cyclists, possibly during specific activities, e.g. while going to school or work. In this case people can be carrying personal air pollution monitors and simultaneously record their whereabouts and activities (Dons et al. 2011). When repeated, these personal exposure data can give rise to more generalized personal exposure patterns which can be used for optimising personal choices or policy measures.

13.3.2 Sensors

The quality of the sensing devices is a clear, but often overlooked aspect in participatory air quality monitoring. Several research groups have developed portable devices, integrating commercially available low-cost gas sensors, GPS and mobile phones (Dutta et al. 2009; Zappi et al. 2012), but according to our knowledge and experience virtually none of these sensors can be used as such to measure outdoor air quality. Snyder et al. (2013) indicate that many commercially available sensors have not been challenged rigorously under ambient conditions, including both typical concentrations and environmental factors. An important deal of the complexity, and associated high cost, of air quality monitoring devices is exactly related to the fact that they have to be highly sensitive, component-specific and independent from external environmental conditions (i.e. weather effects). An overview of the state of the art is given by Theunis et al. in Part 1 of this volume.

Accurate portable instruments are now available for components such as ultrafine particles and black carbon. They can be used by non-specialist users (Buonocore et al. 2009; Dons et al. 2011), but they are expensive which limits their widespread use. Approaches based on these kind of instruments will thus rely on the availability of these instruments at some kind of central repository (at a government agency, a scientific institute or a non-governmental organization). Further below we will illustrate examples of such an approach.

Efforts to use low-cost sensing devices result in additional technical complexity (and cost) at device level or in complex calibration or data processing algorithms, which again bring them into the realm of technical and scientific expertise which is not readily available for the general public but which could be made available for use through some kind of central repository.

13.3.3 Data Collection and Processing

Monitoring strategies depend both on the available monitoring devices and the defined research questions. At this point in time the availability and cost of monitoring devices does not yet allow large-scale effortless data collection. Clear research questions are therefore essential to focus efforts, and monitoring strategies have to de adapt accordingly. In this context we can roughly distinguish between *stationary monitoring* and *mobile monitoring*.

Stationary monitoring refers to measurements at one specific location over a well-defined time window with a fixed measurement instrument. The spatial coverage may range from one specific location to the coverage of a spatial grid. Stationary measurements are well suited for monitoring specific events or locations, or for following up large scale temporal trends, i.e. for pollutants with limited spatial variability. Spatial representativeness depends on the number of deployed measurement devices (which is related to the cost of the devices, and to practical considerations such as safety, permanent power supply or available space, i.e. in busy streets or at intersections) in comparison to the extent of the area that is monitored and the spatial variability of the pollutant.

Mobile monitoring has gained attention with the onset of portable monitoring devices. Mobile monitoring refers to the collection of data along a route. For example, a volunteer performing measurements while commuting to and from his work is performing a mobile data collection. As such systematic spatio-temporal datasets from a route (e.g. a number of streets) over a well-defined time frame (e.g. during the morning peak hours) are acquired. Mobile monitoring allows to increase the spatial coverage of measurements, but at the expense of temporal representativeness (see below).

Mobile data collection can be performed in a *targeted* or an *opportunistic* way. In a *targeted* data collection scheme, volunteers deliberately plan and carry out measurements with a specific purpose in mind. They concentrate efforts in a well-defined area (e.g. a number of streets) over a specific time frame (e.g. during the morning peak hours) in an attempt to get a representative picture of reality. Literature examples of targeted data collection approaches using fixed routes are Hagler et al. (2010), Hsu et al. (2014), Pattinson et al. (2014) and Peters et al. (2014). These examples did not involve volunteers in conducting the measurements but results from these studies concerning the targeted monitoring approach can be extrapolated to participatory monitoring actions with limited numbers of participants. Obviously, with increasing numbers of participants the argument for using a targeted approach to guarantee a good coverage becomes less stringent.

In an *opportunistic* data collection scheme, on the contrary, measurements are collected by volunteers in their normal daily routines. This can be city wardens, parking wardens, street cleaners, bike couriers or postman, but as well commuters that cycle every day to work. The participant does not decide on measurement location and time from his/her interest to monitor a given event. They do not envisage to cover a specific period of time, nor a specific location or route. Opportunistic data collection (ideally) requires measurement devices that measure continuously without any intervention of the user. The planning, efforts and commitment for opportunistic data collection can be relatively low, but it will result in a (possibly) sparse and biased dataset, and entails additional challenges in data quality control, data processing and interpretation. Usefulness of the data will depend very much on the fact whether or not the volunteers cover the same routes and places regularly, and whether all locations and time periods of interest are sufficiently covered.

Data processing of the collected data is needed for various reasons: (1) data cleaning and validation with screening algorithms to remove erroneous measurements, (2) data processing to reshape, rescale, filter, smooth or aggregate the mobile data into meaningful, research question-specific data, and (3) data analysis. For mobile measurements the data validation should be performed on both the air quality as the GPS data. In case of GPS failure for short periods, which is sometimes observed in cities due to shading effects, interpolation algorithms may be used to estimate GPS locations based on previous and following measurements. Errors in air quality data may have different causes ranging from sensor failure to inappropriate use of the sensing device. The selection of data processing strategies depends on the experimental design and research questions driving the analysis.

Van den Bossche et al. (2015) used the same dataset described in 2 (Peters et al. 2014) to develop data processing methods, and draw conclusions on the results that can be expected from limited sets of repeated mobile measurement runs. After allocating all data to street segments of a specific length (i.e. 50 m), they apply a trimmed mean for each segment to reduce the effect of extreme events. Background normalization is applied to account for the day-to-day variability in air pollution.

They conclude that mapping at a high spatial resolution is possible, but a lot of repeated measurements are required: depending on the location 24–94 repeated measurement runs (median of 41) are required to map black carbon concentrations at a 50 m resolution with an uncertainty of 25 %.

Brantley et al. (2014) provide a framework to determine spatial trends of near source air pollution. To minimize the impact of sporadic proximate exhaust, local exhaust plumes are isolated using time-series analysis techniques. Then background estimations are made to isolate local from background components. Including background areas in the sampling routes is one way to obtain background values. Baseline estimations from time series statistics is another approach (Van Poppel et al. 2013; Brantley et al. 2014). Finally, temporal or spatial smoothing is often applied to reduce variation. Temporal smoothing (e.g. 15-s moving average) leads to spatial blurring of the mobile measurements, whereas spatial smoothing is used to aggregate measurements from different times, potentially made under different conditions, to a spatial entity (e.g. a street section or a city block).

13.3.4 Participation

The success of the monitoring strategies will depend highly on the participation of volunteers, i.e. the number of people that can be involved, their (intrinsic or extrinsic) motivation, and the level to which the latter is in line with the objectives and needed data collection efforts. Some monitoring strategies are clearly more demanding than others. Targeted mobile monitoring campaigns will require highly committed participants who are prepared to spend time and efforts to repeatedly cover the targeted monitoring area on the appropriate moments. The planning, efforts and commitment for opportunistic data collection on the other hand can be relatively low, but depend on the user-friendliness of the devices, i.e. the capability for continuous measurements with minimal intervention of the user. In practice monitoring campaigns can be a mix of both with targeted monitoring efforts complementing opportunistic data where needed.

13.4 Participatory Mobile Air Quality Monitoring

13.4.1 Mobile Air Quality Monitoring

Air pollution monitoring on mobile platforms is increasingly applied for exposure monitoring. Mobile measurements are frequently applied as a complementary tool to the stationary air quality measurements at fixed locations, because fixed stations are not capable to depict the full spatial distribution of air pollution over the extent of an urban area. Monitoring instruments have already been installed on all kinds of mobile platforms, such as trams, buses, cars, bicycles or backpacks. Two tracks in using mobile measurements for exposure assessment are encountered in the literature. The larger number of exposure studies applies personal monitoring by directly equipping the study subjects with portable integrated sampling equipment or real-time monitors (see e.g. Dons et al. 2011). A second group of studies addresses the potential of using mobile measurements to construct air pollution maps at a high spatial (and temporal) resolution and to derive exposure to pollutants from these maps (see Pattinson et al. 2014; Van den Bossche et al. 2015).

Deriving high-resolution maps from mobile data requires large quantities of data to represent the range of possible meteorological and traffic conditions (Padró-Martínez et al. 2012) and to aggregate very localized spatio-temporal snap-shots into broader-scale pollution maps. Peters et al. (2014) showed that mobile monitoring can give additional insights in spatial variability and exposure assessment, at a resolution of street level and even within-street level. To be representative and useful for personal or community decision making, mobile measurements have to be repeated regularly, data have to be aggregated over relevant time frames and locations, and carefully interpreted using data handling and expert knowledge to filter out inaccuracies. To increase comparability and reduce the number of repeated runs, measurements can be normalized with air quality data at background locations. These methodological issues are thoroughly addressed in Brantley et al. (2014), Peters et al. (2013), Van Poppel et al. (2013) and Van den Bossche et al. (2015). Both targeted and opportunistic participatory monitoring schemes can have an important role in collecting these large datasets as we will illustrate in the following paragraphs.

13.4.2 Case Study: Exploring Healthy Cycling Routes

In Ghent, a local environmental organization called the Gents Milieufront (GMF), wanted to investigate traffic-related air pollution on some important cycling routes. They set up a *targeted monitoring* campaign during 2 weeks on a selection of urban roads with a total length of roughly 18 km split up in three routes (Fig. 13.4a). On each of these routes a total of 15 repeated continuous measurement runs was carried out.

To collect the data they used airQmap (www.airqmap.com). airQmap is a platform to collect mobile black carbon measurements and to process them into street-level black carbon (BC) exposure maps. airQmap has been designed with usability, autonomy and continuity in mind. It causes minimal nuisance for the person conducting the measurements. This is required to allow unskilled volunteers to collect mobile BC measurements.

airQmap contains a data acquisition part and a data transmission part. The first part consists of a small bag with a GPS (Locosys Genie GT-31) and a portable black carbon monitor (AethLabs microAeth model AE51). The second part is a home station with a netbook and custom-made, easy to use software to read out the

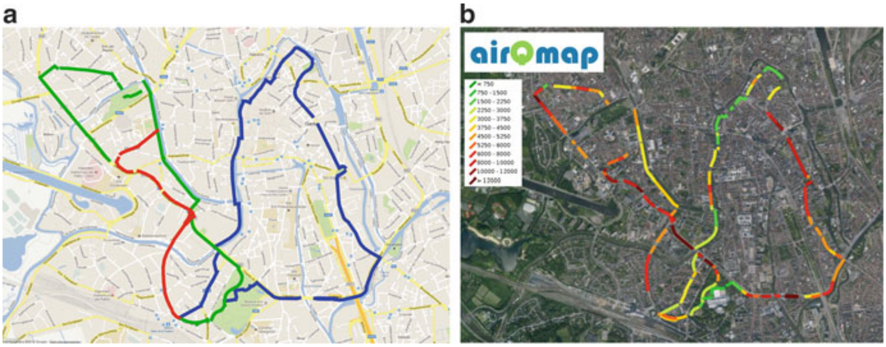

Fig. 13.4 (**a**) Overview of the monitoring routes: routes were sampled between 8 and 9 AM (*green*), between 14 and 15 PM (*blue*), and between 17 and 17.30 PM (*red*) and (**b**) BC concentration map: street-level average BC concentrations (in ng/m^3) (available at http://www.airqmap.com/ghent.html)

measurement devices, keep their clocks synchronized and transmit the data over the Internet.

Data are stored in a central database. Data processing algorithms and visualization tools are linked to the database. The data processing is a cascade of different steps to reduce the noise in the data (using the ONA algorithm, Hagler et al. 2011), to carry out background normalization to account for day-to-day differences in background concentrations, to validate GPS and BC data, to project the data on a street map, and to aggregate the data to street average concentrations (spatial smoothing by averaging measurements per street). The processed data are plotted on an interactive map showing the street average BC concentrations for streets with sufficient numbers of observations. Street statistics can be viewed by clicking on the streets. In addition, a coverage map is build showing the number of repetitions, i.e. the number of distinct measurement series, per street. The maps are shown in a web application (http://www.airqmap.com/ghent.html) and are accessible from most current GIS software through the open OGC WMS service standard.

The selection of volunteers to do the mobile monitoring was organized by GMF. GMF also proposed the measurement routes and a final time schedule was made up in a coordinated and targeted way, taking into account the need for repetitions. A total of approximately 75,000 validated individual measurement points was obtained in a period of one month and a half (26/09/2012–12/11/2012). The measurements were assigned to 181 unique streets, but to a significant number of these streets only few measurements were allocated. This happens, for example, at cross-roads where adjoining streets are crossed and few measurements may get attributed to these streets. Therefore the data analysis and visualization makes use of a threshold for the number of measurements per street as a criterion for inclusion in the assessment. The BC concentrations at these streets were compared and allowed for the identification and ranking of streets and zones according to the measured pollution levels. By comparing street averaged BC values with the BC values obtained at urban background locations, i.e. urban green or park, the impact of local traffic contributions can be estimated. Results were explained by looking at the street topology (openness, presence/absence of separate biking lanes) and traffic volumes. Healthier alternative commuting routes with lower exposure to BC were recommended based on this research. In conclusion, the targeted approach with fixed sampling routes and timings resulted in a high number of repeated measurements in a selection of streets with limited resources (i.e. 1 sampling system, brief monitoring period). Knowledge about the monitoring routes and the way the sampling is performed directly results in lower data rejection in the data validation step.

13.4.3 Case Study: Opportunistic Air Quality Monitoring by City Wardens in Antwerp

In Antwerp a case study was set up in collaboration with the city authorities to explore the possibility to map urban air quality based on an *opportunistic monitoring campaign*. Three teams of city wardens patrolling through the city during a 12 month period used airQmap (2012-07-02 until 2013-06-28). The air quality was monitored on 110 days. The city wardens did not follow predefined routes, they just carried out measurements during their daily tasks. They have a delineated area in which they operate, so in that sense their monitoring efforts were confined to a specific neighbourhood. The monitoring efforts were confined in time predominantly to working hours and weekdays. So, although monitoring did not follow predefined routes, space and time coverage was restricted and far from random.

Correct allocation of the data to their spatial position on the maps proved to be much more challenging than in the targeted monitoring case (4.2). No a priori knowledge on the tracks that are monitored is available. Also, data are not only taken outdoors. The occurrence of indoor measurements led to increased missing GPS values and GPS errors. This resulted in considerable loss of data compared to the targeted approach. In the data validation, approximately 2/3rd of the data is rejected based on uncertain geographical information. Still a large amount of data is still available (222 h) from 540 different streets. Measurements were mostly made on weekdays between 9 am and 4 pm (Fig. 13.5). Distributions were quite inhomogeneous. On Monday and Friday, the amount of data was approximately half the amount of the other weekdays. Important differences are also observed between the different hours of the day.

The BC concentration map that is obtained after data processing and by using a minimum of 10 monitoring episodes on 10 different days per street is shown in Fig. 13.6. Background rescaling was performed based on reference BC data to rescale the measurements over time, i.e. to account for variations in the background BC concentration. Data analysis also took into account the variations in BC

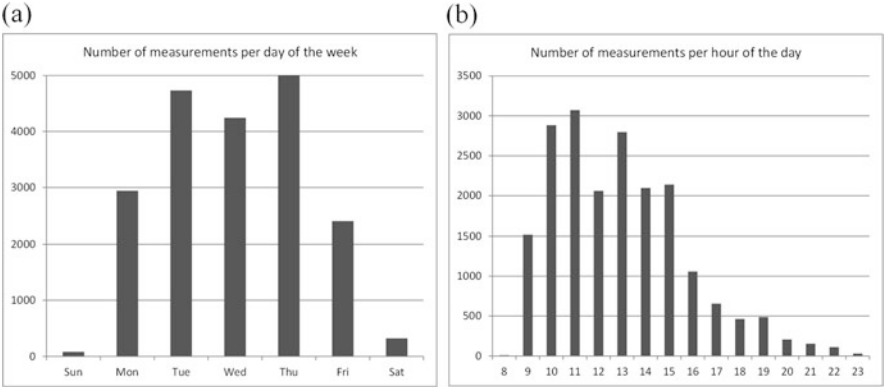

Fig. 13.5 Distribution of the measurements over the days of the week (**a**) and the hours of the day (**b**)

Fig. 13.6 Overview of street-averaged BC concentrations (in ng/m^3) in Antwerp based on opportunistic data collection by city wardens (available at http://www.airqmap.com/cityGuards.html)

concentration per street by using quartile statistics (first and third quartile for low and peak concentrations respectively). Given the opportunistic nature of this case study a quite homogeneous coverage of the area was obtained. Of course, the city wardens operated in well-confined areas in the city mostly during working hours on weekdays resulting in repeated measurements on several locations. Still, further analysis of these data is needed to investigate the impact of spatial and temporal biases in the measurements on the resulting street-level averages.

This experiment was set up with minimal involvement of research staff during the data collection. Having a consistent data set over the long period of time of 12 months turned out to be less evident. A lot of measurements were collected in the first few weeks after which the number of measurement gradually dropped. It increased again in the last 2 months of the campaign after some reminders to the city wardens by the research staff. Good *usability* of the monitoring equipment is crucial. Tasks which look simple at first such as making sure the battery of the measurement device is recharged, changing a filter, or turning of measurement devices after completion of the measurement day seem to go wrong regularly. A little to our surprise, most problems didn't arise in the beginning of the project but after some time, maybe due to decreased motivation. The volunteers in this case study did seem to conceive the monitoring as an extra task to their daily job. When monitoring actions grow from community concerns, decreased motivation may be less of an issue. An additional challenge is the *privacy* of the volunteers. For each second of the measurement days the precise location of the persons is recorded, but this level of detail about their location cannot be made public. A certain level of data anonymization is needed before the results can be made public.

13.5 Conclusions

A conceptual model is provided to frame participatory monitoring initiatives in regard of the sensor availability, the methodology followed to do the monitoring and the form and degree of participation. The interplay between sensors, methodology and participation is determined by well-defined research questions that need to be addressed.

For air quality monitoring, it is possible to set-up sensor networks or mobile monitoring campaigns to investigate the urban air quality at a high spatial resolution. However, measurement equipment is expensive, and the integration into a mobile platform with GPS tracking and data communication facilities is not readily available. Also the advanced data processing currently forms a barrier for its widespread use in participatory science. Nevertheless, literature and the case studies highlighted in this chapter indicate the potential for (mobile) participatory air quality monitoring. Tools exist that allow to get a detailed view on the street level exposure to traffic-related pollution (BC) of cyclists and pedestrians in urban environments based on targeted or opportunistic measurements. Systematic differences in exposure in streets of interest can be detected with a relatively short targeted measurement approach.

At this point in time it seems difficult to rely on a strategy with only low-cost sensors for air quality monitoring in which data are collected, processed and interpreted almost effortlessly. Proper combination of sensors and additional contextual data, and careful interpretation of the resulting data require expert knowledge. However, community participation and citizen science can play an important role in large scale data collection with low cost sensors, in more targeted data collection with sophisticated portable sensors, and in providing relevant contextual information and interpretation. The complexity of air quality research asks for a community science approach in which citizen scientists and regular scientists work closely together to answer specific research questions.

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Chapter 14
Getting Out of Their Way: Do-It-Yourselfers, Sensing, and Self-Reliance

Cindy Regalado

14.1 Introduction

In current practice the various social and environmental concerns of 'lay-people' or 'non-experts' are lumped together and their issues are objectified (Wynne 2007). Multiple constructions, including claims and counter-claims about what the public 'really' thinks and what the 'real public' might be is defined by prevailing institutionalised patterns of power and authority (Cunningham-Burley 2006; Irwin 2006; Marres 2005). Overshadowed by political discourse and by the fierce pressures on scientific institutions to deliver policy agendas that secure the interests of powerful global patrons, which are often justified as an endeavour for 'the public good', the stories of actual people have a limited voice (Lave 2012; Friedmann 1987). Under-representation renders their skills, hopes, and passions unimportant and hence, undervalued and underestimated. This inevitably leads to exclusion not only from the decision-making process but also from taking part in process of actively addressing the issue at stake (problem-solving).

Do-It-Yourself (DIY) and grassroots approaches to scientific investigations such as environmental monitoring have potential to address local concerns in which tools and media act as vehicles for making sense of experiences in our own terms—that is, incorporating different ways of knowing, understanding, and doing (see also J. Theunis et al., this volume). There is evidence that it is through the bottom-up envisioning and devising of methods and through the creation, re-purposing, and use of technologies, that some people are taking a lead applying their civic capacities into scientific research initiatives that challenge and/or question the state

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of things to address issues of concern to them (Jalbert 2011; Wylie et al. 2014). These efforts provide the granularity and nuance that renders them inclusive of local issues, knowledges, politics, and sustainable solutions.[1] Furthermore, this approach provides a means for the development of an adaptive process through which people can discover their needs and capacities, develop and master skills and tools, negotiate their values and identities, and decide their own path of action. This I have termed Publicly Initiated Scientific Research (PIScR). Efforts such as those of the Public Laboratory for Open Technology and Science (Public Lab), a U.S.-based not-for-profit, in the development of DIY tools and approaches embedded in a practice of civic science have lead not only to a shift in the definition of who can do science and what science is for but to a change and re-kindling of a citizen-led and initiated approach to exploration, questioning, and research.

An emancipatory era aided by increased access to tools and information, some claim, is changing the way we consume, share, create, and do (Foth et al. 2011; Nielsen 2012; Schickler 1994). While there are increasing claims as to the decentralisation and democratisation of knowledge and science, technology and participation there is still an evident gap within the DIY approach in engagement with science and technology. Exclusion and exclusion manifest themselves in many ways including, technophobia and technophilia (issues of (self-)trust), validation (issues of legitimacy), skills (mastery and autonomy), and is inevitably linked to larger socio-economic and political contexts. In this chapter I present a conceptual framework for the examination of the interrelated factors that contribute to issues of exclusion and exclusion in PIScR at the individual and societal level and the challenges these pose to DIYers and tryers of DIY.

Based on an examination of the Public Lab, I argue in this chapter that the approach proposed in PIScR is one that questions and transforms how and who can make credible and actionable scientific knowledge by changing and re-appropriating the material technologies used for scientific research (civic techno-science) (Heilbron 1989; Public Laboratory for Open Technology and Science 2011; Fortun and Fortun 2005). While doing so, it also provides a means for the development of an adaptive process through which people can discover their needs and capacities, context and situation, as well as develop and master skills and tools, negotiate their values and identities, and decide their own path of action (Kemmis 2008; Rahman 2008; Fals-Borda 2001). Finally, I illustrate how these attributes of PIScR also reveal, and conceal, a relationship to the larger societal structures within which they operate that shapes and is being shaped by practice.

[1]Eymund Diegel, personal communication about the Gowanus Canal Conservancy's Grassroots Mapping in New York.

14.2 Situating DIY Sensing

> There comes a time in every man's education when he arrives at the conviction that envy is ignorance; that imitation is suicide; [. . .] that though the wide universe is full of good, no kernel of nourishing corn can come to him but through his toil bestowed on that plot of ground which is given to him to till. The power which resides in him is new in nature, and none but he knows what that is which he can do, nor does he know until he has tried (Emerson 2010)

At its core DIY means taking ownership over our lives, having the confidence in our abilities to do, and thus, becoming more self-reliant. In his 1841 essay on self-reliance, Emerson expressed his dissatisfaction with the lack of autonomy among the American population betrayed by a dominant dependence on experts and reliance on institutions—a point we will return to in the next section.

The term 'Do-It-Yourself' and its abbreviation 'DIY' came into use in the 1950s with the advent of hobbyist magazines such as Popular Mechanics and Mechanix Illustrated (McFedries 2007) but DIY in itself is not a new phenomenon nor is DIY a generalisable culture. However, DIY can be conceptualised as both a philosophy and a movement. As a philosophy it stands for freedom from the reliance on social institutions to discover our own motivations within (Wehr 2012) and as a movement, DIY draws from an intellectual infrastructure that allows DIYers to reflect on what it means to do-it-yourself (Morozov 2014). Together these make the foundation for a DIY ethos that is reflected in various DIY manifestos (Frauenfelder 2010; McCue 2012; iFixit 2010).

People across the world are engaging in DIY for a multiplicity of reasons; interests and motivations range from conscious and politicised responses to a complex and fast-moving world, to the pride of having a job well done, to wanting/needing to save money (Wehr 2012). Focusing on DIY as a movement helps us make sense of this social phenomenon, whether it is collective, coordinated, or individual, intentional or not. As Wehr (2012, p. xii) argues, "the collective behaviour of multitudes of people in a particular direction certainly deserves notice". It is a movement which, in recent years, has gone from the margins to the mainstream (Cole 2011).

What characterises DIY sensing in the literature is 'physical computing', that is, the use of programmable devices, often connected via (wireless) sensor networks, that interact with and respond to input from the surrounding environment e.g. sound, light, radiation, gases, etc. DIY sensing, can be linked specifically to the Maker movement, "a rekindled interest in manufacturing and hardware, accompanied by the proliferation of inexpensive or less expensive distributed, democratizing manufacturing tools [that] lifted off in the mid 2000s" (Maker movement 2012). It is precisely this increase in the availability and affordability of platforms and components as well as the vast array of online resources that enables DIY sensing, which many claim is contributing to the 'democratisation' of science, technology, knowledge production, and the web—a point discussed in the next section. There is also an element of aesthetics and artistry involved as it is not just about 'doing-' but 'designing-it-yourself' (Lupton 2006). In this chapter, DIY sensing refers to the use of DIY technology in the broader sense to include not only the tools, such as sensing equipment, but also the reflective process involved in making sense of environmental sensing itself.

Looking at DIY sensing in this way opens up the issue of who controls, consumes, and creates the means for participation in it (Kelty 2005). Kelty's (2005) idea of social imaginaries, grounded in Charles Taylor and Jürgen Habermas' theories on 'the public sphere' (see Box 14.1), helps bring together DIY, sensing, and self-reliance: he explains that social imaginaries are ways in which people imagine their social existence through their practice, how they fit together with others, the expectations that are normally met, and the deeper normative notions and images that underlie these expectations (Kelty 2005). As spheres of common practice, these imaginaries permit us to understand DIY as a form of 'free speech'. In this way DIYers and tryers alike use technologies as a kind of argument to make claims: they make arguments about DIY and they also make arguments through it. DIYers create meanings and express ideas about DIY through discourse but by physically *doing* they also express ideas about the process of *doing*; expressing by *doing* is also a means for ideals to be conveyed, practiced, shared, and repurposed. For example, a map made using DIY aerial photography showing the effect of an oil spill on the seashore habitat conveys the extent of environmental damage, while in a more subtle way, the making of the map relays something about how the makers envision the practice of taking ownership over an issue.

Argument-by-DIY[2] as equivalent and in parallel to argument-by-discourse, whether it is written or verbal, says something about how self-reliance, self-learning, and self-satisfaction takes shape. In this way, DIY provides a voice that not only counts in the decision-making process (see M. Haklay, this volume) and in the problem solving of local issues but also paves the way and shapes the discourse of "taking ownership" and "taking issues into our own hands". DIYers can thus be conceived of as redefining civic responsibility as a call to engage in a critique of the system and on technologies as well as the means to sense, interpret, and change our environment. In the next section I take a closer look at how argument-by-DIY highlights the power of ordinary people's capacity to act as civic agents. I explore what people are able to express through DIY sensing and how the implications of that can be understood in terms of larger social structures. What does DIY as an expressive social imaginary tell us about its ideals, hopes, aspirations, motivations, and what does this reveal (or conceal) about the inclusivity and exclusivity of current practices—for the individual and in terms of the larger societal structure?

[2]Akin to Kelty's (2005) idea of 'argument-by-technology'.

14.3 Technology and the Colonisation of the Lifeworld

Throughout our history technological advancements have led to improvements in the quality of our life (e.g. vaccination), access to information (e.g. printing press), connection with and understanding of the micro- and macrocosms (e.g. microscopes and telescopes), among others. However, over the last century the rate and scale of technological advancements and innovations, as well as the processes by which they are produced, have also contributed to the mystification of a large part of our lives (e.g. electronics and pharmaceuticals).

Digital and mechanical objects aid and mediate our everyday lives, yet, they are for the most part taken for granted; it seems that very few people feel they understand how their devices and artifacts function and fewer yet feel they know much about how these are made, where, and by whom. This ‘alienation’ and ‘mystification’ of technologies was conceptualised more than 150 years ago by Karl Marx, who was critical of the effects that new forms of industrial labour had on society, specifically, on social relations. He explained that in the new labour system, the interactions between the worker, the product, and the consumer, which had previously been of a social nature, were being replaced by wages and prices. According to Marx, in the wage labour system the labourers were separated from what they produced—its quality, meaning, and value; the product is mass produced, sold anonymously in the global market, and hence, it becomes mystified as its origins become unknown or forgotten. Marx argued that when money mediates social relations, we experience detachment: a separation from the fruits of our labour and from what is being produced—there is a lack of appreciation and of personal fulfilment, and a loss of sense of ownership, pride, choice, and even hope is experienced.

Jürgen Habermas, a contemporary sociologist and philosopher in the tradition of critical theory and pragmatism, critiqued and advanced Marx’s ideas of alienation, detachment, and mystification in industrialised societies. He pointed out that liberation from the forces of production and emancipation cannot be conceived by conceptualising labour as the basic category of human liberation; human relations and interactions are ‘subject-to-subject’ in nature, whereas relations between labour and work are merely instrumental, that is, object-to-subject (Finlayson 2005). Additionally, Habermas observed that in small-scale societies people employ their social competences, what he calls ‘communicative action’, to negotiate with each other and create meaningful relations, person to person. For Habermas the concept of ‘communicative action’ entails not only the establishing or maintaining of social relationships between people (Edgar 2006) but it also emphasises his point: people are indeed social agents capable of affecting change. Unlike other sociologists and critical theorists,[3] Habermas refused to accept the pessimistic idea of people as passive victims at the mercy of a powerful force; he rejects that the capacity of

[3] Specifically his tutors Theodore W. Adorno and Max Horkheimer from the Frankfurt School.

ordinary people to debate and challenge authority or the status quo can be wholly suppressed and instead, looks to emerging sources of critical potential such as social movements that appeal their stance.

Habermas contrasted small-scale with large-scale societies and observed that as societies grow and become more complex in their arrangements (e.g. to undertake grand projects such as welfare, national transport networks, a space programme, etc.), larger mechanisms of coordinated actions are established to mobilise the scale of people and resources needed. These great projects have the benefit of facilitating the relatively smooth running of societal functions while relieving the population's competencies to achieve and engage in other, perhaps other more complex activities. However, these 'relieving' mechanisms come at a price. They necessitate increasingly complex networks of highly distributed and asynchronous groups of people. Habermas argues that the approach in these mechanisms, what he calls 'instrumental action' (in contrast to 'communicative action') is characterised by causal intervention with manipulation of the physical world and coercive action. In this sense, instrumental action depends on commonly recognised 'cues' (e.g. laws, monetary value, status), which people use/respond to without the need of resorting to communicative action (Edgar 2006).

Habermas notes that while the instrumental approach is effective when running a complex system, problems begin to arise when "people cease relating to each other [. . .] as communicatively competent human beings, and instead, treat each other as means to an end" (Edgar 2006); the same cues that smoothen the running of society take over the functions and ways of relating with each other in our everyday life. For example, when I walk into a shop, I examine and choose my items (e.g. based on their monetary value) and place them on the counter. The common cue is the price: the shopkeeper conveys it and expects money for it; I pay and leave the shop. Our interaction was mediated by predictable cues and we considered each other mainly in terms of means to an end.

Habermas focuses on the characteristics and effects of these cues and identifies them as 'steering media'. These media function as coordinating and directing mechanisms for the 'system', i.e. the social institutions and structures of our societies: money is the steering medium for the capitalist economy; power is the steering medium for the state administration and related institutions. Power, Habermas argues, functions in a similar way as money "in so far as those who have legitimate power can both compel others to behave in a certain way and can delegate power to others, so that subordinates can themselves control others. Again, communication is not required, providing the chain of power goes unquestioned, and the subordinate obeys the order as expected" (Edgar 2006). For Habermas it is not merely the functions of money and power that pose an issue when they extend outside the system, but what they come to signify in our societies:

> The symbolically embodied amounts of value expended in exchange values [money] or in binding decisions [power] are backed by reserves of gold or means of enforcement [cues] and can be redeemed in the form either of use values [e.g. products] or of the effective realisation of collective goals [e.g. welfare system]. Both the reserves that back them and the real values they are redeemed for are such that they have empirically motivating power

> and can replace rational motivation through reasons [the practice of communicative action]. [. . .] [P]ower needs an additional basis of confidence, namely, legitimation [. . .] [and] requires an advance of trust that not only 'compliance' – a de facto obedience to laws – but 'obligation' – a duty based on the recognition of normative validity claims (Habermas 1987).

Actions within a system are governed by a set of standards and rules that simplify our interactions (e.g. a legally binding contract that dictates my relationship with my landlord). These rules, or normative validity claims have a high degree of consistency and uniformity, which makes them easier to follow, implement, monitor, and reinforce. What characterises the system in Habermas' view is having its own autonomous logic rooted in fairly stable bureaucratic institutions that have inertia and are difficult to change. Once complex societies are organised through systems, the autonomous logic of those systems will begin to direct what is possible and how anything is achieved within that society. For example, who is eligible for welfare benefits or who is allowed to be legally married. With this framing, it is easier to see the implications of what Habermas calls the 'colonisation of the lifeworld': what is not conceived of by the system will either be absorbed into it or marginalised. The colonisation of the lifeworld is a process by which the actions of those subject to the system places an increasing limit to their freedom (of movement, thought, speech, action, and other choices). For example, when social interactions are replaced by wages and prices the opportunities that promote inquiry and reflection, as well as the mechanisms for transmitting and interpreting ideas and narratives become supplanted. On a grander scale, the effect of colonisation can result in the perpetuation of illusions, socially necessary, yet false beliefs assumed to be true because virtually all members of society are somehow made to believe them" (Finlayson 2005) such as the general belief in that new wave of web-based tools and ICT is a force ushering democratisation but in practice, there is still a massive digital and technical exclusion underpinned by larger systemic issues.

Habermas argued that through communicative action people question ideas and justify their own arguments through appeal to reason. Linking back to his argument in defense of people's capacity to act, he employed the term 'lifeworld' to highlight the underestimated competence of ordinary people as civic agents and to correct the bias that overemphasised the coercive power that the structures and arrangements of society have on the individual. Theodore Adorno's idea of a 'totally administered society', which Habermas wants to rectify, was representative of the dominant conception of the early members of the Frankfurt School of Thought and American sociologists of the 1960s. Habermas was concerned about the impact that autonomous bureaucracies and the capitalist economy of large-scale and complex societies was having on individual freedoms. In the backdrop of a critique of Marx, he also saw that society was created and sustained by human actions. For Habermas, the lifeworld represents the everyday world that we share with others; it is a type of social imaginary through which we envision our social experiences and which provides the cultural resources used to make sense of, cope, and adapt to life's circumstances (Edgar 2006). It symbolises the informal, unmarketised domains of social life: networks of family and friends, culture, and political life outside organised parties, mass media, voluntary organisations, etc. (Finlayson 2005). It is in these arenas that people interact—they question, network, reflect, discuss, and learn. Communication is the medium in the lifeworld[4] by which these interactions unfold as conversations or exchanges both harmoniously and conflictually—through verbal or written discourse and by physically doing. Together, these interactions create a 'stock' of shared assumptions, reasons, and background knowledge, which people constantly transmit, adapt, and transform to create new and different knowledges, skills, and competences to negotiate and maintain social relationships. These relationships can be sustained in small-scale societies, where people can interact face to face, converse, negotiate, and reach an understanding. However, when populations grow and amalgamate the same instrumental requirements, the rules or normative validity claims, on which they depend undermine the functions of the lifeworld as we begin to treat each other as means to an end.

Hence, while the lifeworld is conducive to autonomy and in it people pursue self-chosen ends, in the system the goals are predetermined and actions are deliberately taken (by coercion or force) to achieve them. When the instrumental practices in the system infringe upon the system—from dictating our legal status and relationship to the state, to standardising tests in schools and preferentially legitimising certain forms of knowledge over others—Habermas argues that certain 'social pathologies' arise such as loss of meaning, withdrawal of legitimation, anomie, destabilisation of collective identities, alienation, and withdrawal of motivation. Below we take a look at the way we can conceptualise the colonisation of the lifeworld and the challenges for DIYers.

14.3.1 Conceptualising Issues of Inclusion and Exclusion: Challenges for DIYers and Tryers

For Habermas 'colonisation of the lifeworld' was the problematic result of what can be described as deliberate and predetermined actions, useful in efficiently coordinating complex systems in large-scale capitalist economies, but detrimental when replacing every day social interactions, that is, taking over the mechanisms for creating meaning and understanding between people. I would like to draw attention to four interrelated factors that contribute to the phenomenon of colonisation of the lifeworld (Fig. 14.1). These factors constitute the elements of a conceptual framework for the examination of issues of inclusion and exclusion in PIScR at the individual and societal level and the challenges these pose to DIYers and tryers of DIY:

- *Symptoms of the State:* The generalisations, at the societal level about public's interests, abilities, passions and hopes by 'experts', society, and the public themselves.

[4]Whereas money and power are the media for the system.

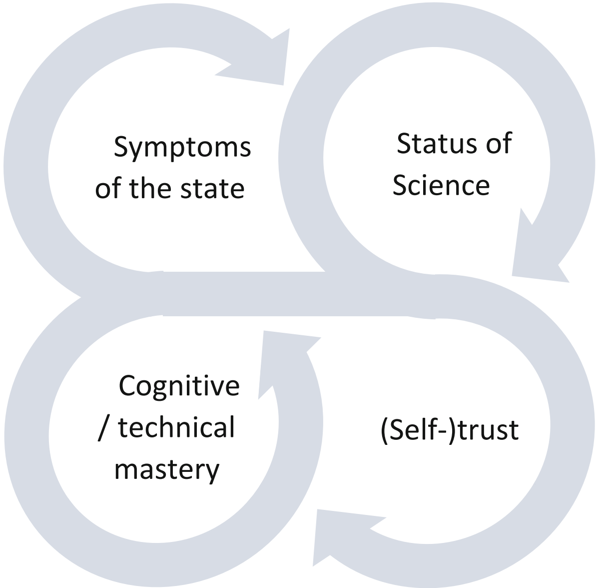

Fig. 14.1 Elements of the conceptual framework in issues of inclusion and exclusion in PIScR. Interrelated factors that contribute to the phenomenon of colonisation of the lifeworld. The symptoms of the state's instrumentalist mechanisms directly affect the way science is done/perceived, which in turn influences people's (self-)trust, hopes and actions, as well as their reaction towards and engagement with science and technology. These combined, have in turn a cyclical effect on the state's policies and strategies, which influence the status of science and the public arena at the individual and societal level

- *The status of science:* The institutionalisation of expertise and the way 'science' is perceived by practitioners of science, the state, and the public.
- *(Self-)trust:* The discourses and actions undertaken by the public, as individuals and groups, with regards to taking ownership over issues.
- *Cognitive/technical mastery:* The multiple levels and mechanisms of exclusion that have to be mastered to be able to contribute to and manipulate the system.

I now move on to discuss each of these factors in light of the issues of inclusion and exclusion framework in Fig. 14.1.

Box 14.1: The public sphere as ideology
The public sphere is "an intermediary between the public realm of the state the private interests of individual members"—"not merely as a way to bring together the voices of many private individuals but also in so far as it facilitates the articulation of the individual's sense of self". As an ideal, publics interact

(continued)

in the public sphere, where "open and rational debate between citizens form public opinion". However, "while it articulates itself in terms of an ideal such that all citizens may contribute to the debate, in practice, that ideal is compromised"—the working classes are excluded and this therefore entails that a number of fundamental issues are not only excluded from the debate but are not politically recognised (Edgar 2006).

Following Edgar's (2006) analysis on Habermasian thought, let's then argue that the content of the ideology of the public sphere is symptomatic of the concerns of the oppressed. Ideologies have utopic content—like dreaming of a better world. However, just as psychoanalysts find clues in their patient's dreams as to what bothering them rather than taking the dreams literally, so can ideologies, as imaginaries, be treated as symptoms of the state and the societal context in which it is conceived, thus providing important clues as to the forms of oppression taking place. These 'clues' provide guidance as to what can be done to remedy and change the situation.

Symptoms of the State The generalisations, at the societal level about public's interests, abilities, passions and hopes by 'experts', society, and the public themselves.

If the contents of a particular culture or practice is treated an ideology (see Box 14.1), that is, by seeing it as a determinant response socio-economic and political oppression, then we are able to search and seek in that practice the resources to understand and expose the injustice of that society. This scrutiny is not only a criticism of its content but also an analysis of its origin and motivation. We become compelled to ask how are ideologies transformed into realities (Edgar 2006); whose ideals dominate; and what do ideologies conceal as they reveal?

In current practice the state (central government or authority) supports and is sustained by mechanisms that coordinate the smooth running of our societies. As discussed in the previous section, issues arise when the instrumental approach (efficient means to an end) embedded in these mechanisms interferes with the way we create meaning and relate to each other in our everyday lives. What does this practice reveal about the welfare state as an ideology based on the democratic "principles of equality of opportunity, equitable distribution of wealth, and public responsibility for those unable to avail themselves of the minimal provisions for a good life" (Welfare state 2014)?

Let us assume that the social/political/economic/judicial arrangements of the state are perhaps too complex to be fathomed as a whole by any individual or small group and that this might partly explain why the system appears difficult to be significantly changed. If the colonisation of the lifeworld is partly symptomatic of this semi-fatalistic conception; that is, the underestimating and undervaluing of ordinary people's competence as social agents (by 'experts', society, and even themselves) to fathom and respond to the complexities of the system is symptomatic of the state's arrangements,[5] then it can also be argued that the DIY movement, consciously or unconsciously, is a symptom of the colonisation of the lifeworld: it is a politicised response to state and market or in Wehr's words, "DIY is an attempt to decolonise the lifeworld" (Wehr 2012).

Responses to social complexity, including the most common approaches to public engagement are unavoidably linked to the particular institutionalised patterns of power and authority within which they are conceived (Winner 1986). This is problematic because in current institutional practice this approach not only ignores the complex challenges of sustainability in our time but also undermines the needs, knowledges, ingenuity, and ability to respond of a large portion of the population.

One of the challenges for DIYers at the larger societal scale is the way that they are generalised. When addressing 'public concerns', and especially coming to terms with grassroots initiatives, the question revolves around what qualifications people have to engage with expert issues or how much they must be educated to bring them up to standard (Wynne 2007). There is still a pervasive normative process led by 'experts' who determine what the relevant 'public issues' are and hence, know what the pressing 'public concerns' are (Wynne 2007). This highlights the ultimate power that governmental "control over framework for engagement" brings (Irwin 2006) and is exemplified by institutional strategies of public engagement, which focus on 'public understanding of science', 'public acceptance of science', and 'increasing scientific literacy' (Shaw 2002; Ruivo 1994; Gauchat 2010). While research and efforts are being undertaken to give more voice to 'lay' people and integrate public values into policy debates (Rowe 2005), the issue is still being approached top-down. This includes manipulation and tailoring of information (Mooney 2000) to avoid 'technical uncertainty' from becoming 'social uncertainty' (Cunningham-Burley 2006; Irwin 2006) while keeping true to underlying, often vague, and therefore unquestioned agendas (Lave et al. 2010). While the goal is to achieve collectively desired and predefined goals (Habermas 1987) such as 'economic growth', the complex and seemingly essential instrumental mechanisms to bring these goals about, as explained above, impose external constraints on action by individuals, including DIYers.

Another challenge for DIYers is that current strategies for public engagement often target and prioritise the open-minded, or 'innocent', members of the public over those who have existing 'activist' views thus, leading to a model of democracy in which polarisations are avoided via marginalisation (Irwin 2006). In view of a government enthusiastically subscribed to a 'science-led society' (the powerhouse of innovation) "what scope can there be for dialogue when the direction is already set?" (Irwin 2006).

Habermas observed that societies embedded in these top-down practices have populations experiencing a debilitating sense of disconnection and anonymity in

[5]For example, the state's arrangements take the shape of institutional strategies for public engagement and the customary reductionist top-down approach to managing social and biophysical systems.

which we question our ability to contribute and to make a difference; we feel that societal structures are too difficult, too large, and too pervasive to change. However, while some of these institutional strategies have been undeniably successful at addressing large-scale issues (e.g. environmental conservation based on crowd-sourced data collection), there is evidence that some grassroots efforts, including DIY practices in environmental sensing are not only questioning the system but also challenging the larger societal structures that underpin it. An example of this is discussed in the next section, 'The power of DIY'.

The Status of Science The institutionalisation of expertise and the way 'science' is perceived by practitioners of science, the state, and the public.

As discussed in the previous section, the professionalisation of science[6] has alienated and even discouraged people who might consider their inquiries not up to the 'standard' of 'real' science. As early as the onset of laboratory science in the mid 1800s people echoed Emerson's critique: "I am ashamed how easily we capitulate to badges and names, to large societies and dead institutions". Most professional scientists follow rigorous benchmarks and standards and their work is governed by structures that provide continuity, efficiency and can guarantee a degree of quality. There are numerous examples where this arrangement has consistently facilitated astonishing accomplishments (Good and Shymansky 2001). However, it can be argued that this same rigid structure impedes questioning the structure itself as well as the system within which it operates (Winner 1986). Some scholars further critique the status of professional science legitimised as the singular authoritative voice informing policy for the greater good justified as *the* superior public knowledge (Wynne 2007; Friedmann 1987). However, as Freidson (1986) pointed out, knowledge as well as "the professional groups representing disciplines or bodies of knowledge that claim the right to control particular areas of social policy that affect particular areas of human life" need to be scrutinised. Freidson raises issues about knowledge and power and critiqued that 'knowledge' is often treated as a disembodied entity with "its content constructed by quoting textbooks, speeches, or articles in professional or lay periodicals". However despite the semblance that the knowledge that is so firmly asserted by authorities and on which much of validity and history relies, thus outweighing all other kinds of knowledge, it is not as canonical as it may appear. Freidson (1986) explains:

> [d]own at the level of everyday human experience, in schools, prisons, scientific laboratories, factories, government agencies, hospitals, and the like, formal knowledge is transformed and modified by the activities of those participating in its use. Thus the paradox that, while the institutionalization of knowledge is a prerequisite for the possibility of its connection to power, institutionalization itself requires the transformation of knowledge by those who employ it. The analysis of scientific and scholarly texts can be no substitute for the analysis of the human interaction that creates them and that transforms them in the course of using them in a practical enterprise.

[6] A phenomenon that has also occurred in other practices such as the Arts.

Critical of the ideological dominance of ‘science’ as a singular type of knowledge, Habermas defined ‘scientism’ as science’s belief in itself: “that is, the conviction that we can no longer understand science as one form of possible knowledge, but rather must identify knowledge with science” (Habermas 1986). In response, and to dissolve the boundaries of knowledge privileged as ‘scientific’ Habermas identified three inclusive categories of processes of inquiry namely, the empirical-analytical sciences, which incorporate technical-cognitive interests for the purpose of enhancing prediction and control; historical hermeneutic sciences, which incorporate a practical cognitive interest with the purpose of improving mutual understanding; and the critically oriented sciences, which incorporate emancipatory cognitive interests with the purpose of transformation. This was his way of calling attention to the need to acknowledge different ways of knowing and understanding. Many decades later the critique is sustained and is particularly relevant in the current state of Global Climate Change, addressing sustainability and biodiversity issues, and in a paradigm in which the usual approach to managing social and biophysical systems is to simplify them to ‘objective’ models and controlled experiments that reduce uncertainty (Irwin 1995; Funtowicz and Ravetz 2003). Currently, this approach is undertaken by institutionalised science regimes (Lave et al. 2010). This approach ignores the challenges of sustainability in our time in which facts are uncertain, values are in dispute, stakes are high and decisions are urgent (Funtowicz and Ravetz 2003). This can be conceptualised as the problematic encroachment of the ‘system’ onto the ‘lifeworld’: problem-solving based primarily on institutionalised and professionalised science practices hinders not only our understanding of the complex and multi-scale web of emerging problems but also the conception of new methods for their solution by excluding the creativity, skills, and competence of a large portion of the population.

Issues of (Self-)trust The discourses and actions undertaken by the public, as individuals and groups, with regards to taking ownership over issues.

At the core of many of our accomplishments as a human species is connection to others, our environment, and through this, we construct our realities (Haste 2004; Brown 2010). As perceptual and susceptible individuals, we are open, consciously and unconsciously, to messages, ideas, and concepts that permeate and imprint our psyche and affect how we construct beliefs, which based on past experiences direct our actions and opinions (Friedmann 1987). Akin to Haste’s (2004) conception of the ‘Powerless Pessimist’, the ‘Learned Helplessness’ model assumes that under most conditions a person will attribute a cause for life events, both good and bad (De Saintonge 1998). Those who feel that they are the cause of things going wrong, that this will always be the case no matter what they do, and that this propensity will affect most aspects of their life, become hopeless and depressed and may give up trying to achieve (Abramson et al. 1978; Murphy 1980). A predisposition to feel that *others* control the good events in life can have the same debilitating effect (Seligman 1972).

Meanings and understanding about the world are used as points of reference, which also determine an individual’s ability to adapt to situations. If indeed, our education systems is stifling the individual talents, abilities, and creative thinking of too many (Robinson 2009) and if experts' opinions of the public is that of an ignorant,[7] irrational,[8] and incapable[9] people, then we might run the risk of actually believing it (Lorenzoni et al. 2007; Wallerstein 1992; Bangerter and Heath 2004). The belief that, as individuals, there is nothing we can do because, for example, the system is too big to change, and that even if something does get done it will all be for nothing, is a debilitating and disempowering notion (Seligman 1972; Immerwahr 1999). The question of why people seem to not take initiative is not asked as much as how people ought to be engaged, as seen above. In understanding the encroachment of the lifeworld by the system, these questions highlight a monumental barrier to citizen initiated and led research practices. However, as Lertzman (2012) points out, it is not apathy that we see here—that is a myth—what needs urgent attention is an acknowledgement of our anxieties ("what is going on?"), our ambivalence (competing desires and drives), and our aspirations (I want to do something about it) coupled with approaches that "meet people where they are at, not where we want them to be". This realisation also applies to our relationship with technologies and the related processes of cognitive and technical mastery.

Cognitive/Technical Mastery The multiple levels and mechanisms of exclusion that have to be mastered to be able to contribute to and manipulate the system.

The reputation of web-based tools and technologies as 'democratising' has received tremendous media coverage (see Wired, CNS, Forbes, Popular Mechanics for a few examples) and has been embraced by academic and governmental institutions (e.g. ICT4D). However, this eager hype has also undermined its critique. The reality of participation inequality, as presented in Nielsen's (2006) seminal report, is staggering: there is a 90-9-1 % ratio between lurkers, occasional contributors, and heavy contributors respectively, for all large scale, multi-user, social networks. When compared to the ratio for Wikipedia users, the figures are striking: 99.8 % lurkers to 0.2 % occasional contributors to 0.0003 % heavy contributors.

The 'cultures of participation' (CoP) model originates from a critique of a culture that makes a clear distinction between producers and consumers and which has promoted a consumerist mind-set through media, artefacts, ways of living, learning and working (Fischer 2011). Fischer posits that CoP can address this trend through an approach that aims at the democratisation of design. The transition within CoP transforms passive consumers into active decision-makers as they become aware of possibilities, begin making contributions, organise content and mentoring, and

[7] See Irwin (2006), Wegener and Petty (1998), Friedman (1998), Ziman (1991) and Wynne (1992, 2006) for discussions about conceptions of 'public ignorance'.

[8] See Freudenburg (1993), Furnham (1992), Michael and Brown (2005), Eden (1998), Stilgoe (2007) and Barnett et al. (2010) for discussions on construction of 'publics' and public irrationality.

[9] See De Boer et al. (2005), Burningham et al. (2007), Besley and Nisbet (2013), Bazelon (1981) and Shrader-Frechette (1990) for discussion on the public's capacity to understand and engage with science.

finally become meta-designers who extend the range of the environment. They become smart citizens that take advantage of smart tools to monitor, visualise, and change their behaviour, for example, regarding their energy consumption.

This and other approaches (e.g. (Kuznetsov 2013; Millicevic 2007) speak to the requirements of initiative-taking both in terms of technical aspects and mindset: there should be fertile ground that allows anyone to contribute when they want to; all that is needed is a group and technical infrastructure (Fischer 2011). Specifically arguing for science, Nielsen (2012) holds that people are smart and interested enough and thus, all that is lacking for people to make a contribution is more web-based tools that give people opportunities—tools such as the online crowd-sourced citizen science projects such as Galaxy Zoo and FoldIt. In the span of a generation, he argues, these tools have helped to redefine who can do science and what science is. They democratise science because "online tools are institution-generating machines" (p.158) that have the imaginative and creative *potential* to address the pressing problems of today. The key word here is 'potential'.

Haklay (2013) brings to question the generally accepted and often celebrated assumption that online technologies, such as participatory web-based geographic information tools, are bringing on a new wave of democratisation. Loosely defined around ideals of participation and access for anyone, anywhere, anytime, this assumption is based on potential rather than the actualisation of democracy. Indeed, the potential of web-based technologies and tools to bring about radical change should be applauded, as in the case of projects such as Hole-In-The-Wall in India (http://www.hole-in-the-wall.com/).

However, in models like CoP there seems to be an assumption that 'if you build it they will come' without the need for questioning the very foundations on which they are built. That is, the politics and inherent mechanisms of exclusion embedded in technologies should also be acknowledged (Winner 1986; Habermas 1986; Haklay 2013). Haklay (2013) points out three issues. First, in order to participate people need access—and many are already excluded at this point, technically and digitally. Second, people's "ability to stretch the functionality and capabilities of a given system beyond those that are provided by its creators" is limited by various factors including dedicating time to gain the knowledge and skills needed to control the tool/technology and developing the expertise and mastery needed to create new systems capable of opening new political and social spaces (Haklay 2013). Third, beyond who can use these technologies, "[t]he control over the information is kept, by and large, by major corporations and the participant's labour is enrolled in the service of these corporations, leaving the issue of payback for this effort a moot point" (Haklay 2013). And as Morozov (2014) points out:

> [O]ur institutional imagination has stalled, and with it the democratizing potential of radical technologies. We carry personal computers in our pockets —nothing could be more decentralized than this!—but have surrendered control of our data, which is stored on centralized servers, far away from our pockets. The hackers won their fight against I.B.M.—only to lose it to Facebook and Google. And the spooks at the National Security Agency must be surprised to learn that gadgets were supposed to usher in the "deinstitutionalization of society.

The overwhelming focus on technologies, institutions, and the system at large has implications for people's agency and self-reliance, as Emerson (2010) denounced more than 170 years ago; people's competence, interests, and passions are compromised by a tendency to assume unawareness and an underestimation of their capacity to take issues into their own hands without the recourse to powerful web-based tools. I have discussed how the state, at the larger societal level, the status of science, issues of (self-)trust at the individual level, and the issues of cognitive and technical mastery all contribute to the 'colonisation of the lifeworld'. These four combine and create complex conditions that both hinder and enable people to take part in shaping their lives. However, it is these same factors that inspire and even propel people's initiative-taking. Technologies, as argued above, have a dual function: they can create dependency through instrumental use but as claims, whether it is argument-by-discourse or argument-by-DIY, they can also spur autonomy and create new meanings, statements, and stances. Next, I exemplify some of these efforts.

14.3.2 Publicly Initiated Scientific Research and the Power of DIY: Public Lab

There is a proliferation of literature about how to engage in DIY and the literature on DIY as a phenomenon is steadily growing, especially on DIYbio.[10] However, literature on the context, significance, and impact (both at the societal and personal levels), especially for DIY environment sensing, is scant. What we do know is that it is happening in all forms and scales, evidence of which can be found with simple searches online (e.g. backyard observations).

The spectrum of DIY environmental sensing is diverse and includes individual DIYers slaking their curiosity about themselves and their immediate environment; individuals working collectively to address issues in their communities; people trying to incite awareness and behaviour change (Millicevic 2007; Kuznetsov and Paulos 2010); and DIYers developing tools to get these things done.[11]

The initiative I describe below exemplify DIY environmental monitoring as decolonisation of the lifeworld at the intersection of social, political, economic, and technical complexities highlighted above as 'symptoms for the state', 'status of science', 'issues of (self-)trust, and cognitive technical mastery. These initiatives are conceived of as two approaches namely, activities initiated by the public and actives inciting engagement in DIY.

[10]DIYbio combines an open source ethos, with a DIY will to do things and the joy to mess with biological matter (Delgado 2013) outside of professional settings (Kuznetsov et al. 2012)—a creative proof of the hacker principle (Ledford 2010).

[11]For a fuller review, discussions, and examples of DIY environmental sensing see Peterová and Hybler (2011), Heggen (2013), Gabrys (2012), D'Hondt et al. (2012) and Burke et al. (2006).

We can consider PIScR as a way of applying our civic capacities; it is the bottom-up envisioning and devising of approaches and tools that ordinary people apply to question and challenge the state of things and thus, change what is happening in a particular situation. In Habermasian terms, PIScR highlights ordinary people's capacity to act—to take issues into our own hands as a process of sense-making and investigating in our own terms. And the latter serves to highlight key aspects of DIY. As with DIY, PIScR is self-driven and self-directed and research is done independently from (but not necessarily despite of) experts (Wehr 2012; Atkinson 2006). Like DIY, a solid definition of PIScR cannot and perhaps should not be pinned down. Nevertheless, as discussed above, both DIY and PIScR need to be understood in terms of our histories, culture, and the socio-economic and political forces around us, as well as our technological (digital, web, video, etc.) conditions (e.g. ubiquity). Reasons for engaging in PIScR are as varied as the people involved—it provides a means to be self-reliant (as a welcome or unwelcome necessity), to voice concerns, to express oneself, to take issues into their own hands and take action, etc. At its core, the nature of research in PIScR is not very different from academic or institutional research: those engaged in PIScR carry out an investigation or enquiry, they conceptualise the issue, envision, learn about, and try different approaches to make sense of what it going on; they make observations, devise solutions, approaches, and ideas and gain mastery and autonomy along the way. There are numerous examples evidencing 'learning from mistakes' and trying various approaches in project entries in online platforms such as Instructables.com and Publiclab.org.

Below I illustrate what PIScR does to people and what people do with it. Specifically, in terms of DIY sensing and self-reliance, I evince how the way that Public Lab, as an example of PIScR, portray themselves and define their practices tells us about the power of DIY to question, transform and provide the means for others to discover, share, and take action. Furthermore, I illustrate that their approach in itself reveals and conceals issues of inclusion in PIScR in relation to the larger social structures within which they are contextualised.

14.3.3 The Public Laboratory for Open Technology and Science: In Short

Originally spurred as an action to tackle the unaddressed environmental damage of Louisianan coastal wetlands caused by the British Petroleum oil spill in 2010, Public Lab was founded in the United States by a group of people who identify themselves as doers, innovators, technologists and concerned citizens. They ground their work on the conception of 'civic science' as defined by Fortun and Fortun (2005). Akin to Stilgoe's (2009) idea of Citizen Scientists as "people who intertwine their work and their citizenship, doing science differently, working with different people, drawing new connections and helping to redefine what it means to be a scientist", in a Civic

Scientist's practice different modes and products of sense-making come together to question the state of things rather than simply serving the state (Fortun and Fortun 2005).

Public Lab defines itself as an open-source civic science initiative. Their efforts fill in a gap between the scientific establishment and everyday issues; they seek to address the lack of tools, knowledge, and confidence in our abilities to do so that we can "independently assess information that is handed down to [us] by perceived experts, especially with regard to environmental issues" (Public Laboratory for Open Technology and Science 2011). What this reveals about Public Lab's activities is the role of their practice plays in the larger context. It is a response to the system—as challenging and fulfilling a purpose when the relevant state authorities are not there to satisfy those functions or those functions are in opposition to what the community seeks.

Today, as a not-for-profit, Public Lab provides technical support and how-to guides much like other DIY platforms, but they also consider "high-veracity data methodologies and reproducible results from experiments conducted by well-supported (yet non-professional) investigators" to be a central goal (Public Laboratory for Open Technology and Science 2011). This points to a challenge to the status of institutional science—or as Keysar, a Public Lab community member, expressed it: "Public Lab's definition of civic science places scientific inquiry at the heart of civic life, by bypassing technical barriers which necessitate the "professionalization" of science" (Keysar 2014). Members of the Public Lab community often see their contributions as more powerful that expert knowledge:

> We had a breakthrough when Gulf Restoration Network was able to convince Louisiana Department of Environmental Quality, based on kite photography that a petroleum coke[12] terminal in lower Plaquemines needed to be dealt with. [. . .] The terminal has been dumping into the Mississippi River for decades, and Gulf Restoration Network had been reporting on the waste for a year, but the detail of the kite photo is what it took to convince our enforcement agency to act (Eustis 2013).

Since their inception Public Lab has built a community that collectively prototypes affordable DIY tools and methods for environmental monitoring and other applications. They share insights, problems, and results in the spirit of an open source ethos both online through wikis and research notes in the Public Lab website and offline through community projects and gatherings, and their printed newsletters. This speaks of issues trust; the members of the wider community see this as a technical and intellectual infrastructure that strengths and supports what they do. Practically and technically, this manifests itself by way of feedback and collaborative tool development, and intellectually by way of sharing and building on each other's work and thereby connecting it to a larger social context, thus "rendering it part of a global movement for environmental and civil rights" (Keysar 2014).

[12]Petroleum coke is a byproduct of oil refining that is burned for fuel in countries where air standards are not as high as the United States (Eustis 2013).

Their manifesto is simple: "DIY aims to make technology something anyone can develop; Public Lab aims to make scientific research something anyone can do well. To make something oneself is to have a sense of ownership of it, and we extend this sense to scientific tools and data" (Public Laboratory for Open Technology and Science 2011). To this end, their approach is one of first-hand data creation and analysis through which community researchers build expertise in critical thinking and technologies with broader application to their roles as civic participants. Through their website and face-to-face activities Public Lab now functions as an organised driving force that promotes and incites DIY research for environmental health. And like a snowball effect, the tools that were collaboratively prototyped in Southern USA in the advent of an environmental injustice are now being used and repurposed for a wider range of initiatives. PIScR within the Public Lab takes on a multitude of forms. Examples include aerial photography using kites and balloons for environmental sensing (Fig. 14.2) and social mapping (Fig. 14.3).

Beyond their instrumental utility, Public Lab tools are also used as a way of learning to work together and reimagining contested spaces (see Keysar 2013). This speaks of fulfilling potentials; having the Public Lab tools as open-source prototypes online makes them accessible and gives them exposure (much like with peer-review) from which the larger community can learn from. Apart from enabling

Fig. 14.2 Using a camera attached to the line of a kite people are able to take aerial photographs. The unique perspective enables gathering of evidence for environmental phenomena such as forest damage. *Source:* Cindy Regalado and Publiclab.org

Fig. 14.3 DIY aerial mapping is a powerful tool for understanding and transforming places. Jerusalem-based Hagit Keysar uses aerial imagery to enable dialog about contested spaces between Palestinians and Israelis. *Source:* Publiclab.org

the merging and enrichment of ideas, this exposure also points to unaddressed issues within the Public Lab itself. Both founders and community members of Public Lab acknowledge issues of cognitive and technical mastery; data collection is one thing—framing issues and making sense of that data is another matter. Engaging with data to further your investigations and refinement of your tools requires commitment, patience, and time—a lot of time. A Public Lab community member explains:

> With Public Lab equipment, it is quite easy to collect a thousand map photos in an afternoon and have fun doing it. The fun part ends there for most people, and 90% of the work remains to be done. Sorting and selecting images is tedious and requires facility with software and a big hard drive.
>
> Stitching in Mapknitter[13] is slow and requires patience, practice, and attention to detail. Large projects require an alternative to Mapknitter (e.g., Photoshop) which have fiscal, hardware, and training requirements (Public Laboratory for Open Technology and Science 2013).

The Public Lab approach recognises and integrates different goals of inquiry namely technical, practical, and emancipatory. In Habermasian terms, they seek to provide empirical data and the technical means to produce it so as to "make credible and actionable scientific knowledge" (Public Laboratory for Open Technology and

[13] Mapknitter is the online open source Public Lab platform for making maps from composite aerial images.

Science 2011); in their practice, they also seek to develop DIY sensing tools and approaches as a way to enable and instigate dialogue and improve mutual understanding; and they seek to remedy situations perceived as unjust and question who and how we can take issues into our own hands. The experiences and reflections gained by the members of the Public Lab community extend out to their different contextualised social imaginaries, connecting the individual with a multiplicity of larger societal structures. Through the creation and sharing of accessible and adaptable tools and through the development and nurturing of an open community in which people can discover and extend their capacities Public Lab reveals and critically acknowledges the complexity and limitations of their practice—and by doing so they open up possibilities to transform it.

14.4 Getting Out of Their Way: (De)colonisation of the Lifeworld and Re-appropriating Our Ability to Make Sense of the World

The essence of DIY is one of self-: self-reliance, self-learning, self-satisfaction. Taking ownership is a powerful experience and it is often linked to a realisation that makes us question what happens around us: Doing-it-ourselves incites us to figure out things by ourselves, to do things that have not been done before (by us or even anyone else), and to challenge who can (or should) do it and how. For example, who should take charge of environmental monitoring and who can hold polluters accountable? According to Irani (2008), when it comes to designing-it-yourself, the approach empowers individuals with the means and tools to get their ideas taken seriously; it encourages people to prototype new ways of thinking and living, at any scale; it enriches our ability to respond.

In this chapter I presented a conceptual framework for the examination of issues of inclusion and exclusion in the practice of publicly initiated scientific research connecting four interrelated factors, namely symptoms of the state representing the complexities of larger societal structures, the status of science conveying the institutionalisation of expertise, issues of self-trust representing the discourse and action of PIScR at the individual level, and the opportunities and limitations of cognitive and technical mastery. Using Public Lab as an example, I have argued that PIScR is an approach that provides the means through which people can engage their manifest and latent capacities and develop and master skills for self-reliance, that is, for understanding and taking issues into our own hands. PIScR in this sense represents an approach that acknowledges people's skills, abilities, stories, and hopes and the need to not only include but encourage people's initiative-taking and trust in themselves and their efforts by, in essence, getting out of their way.

The examination of PIScR reveals the relation of practice, both in the way it is exercised and the rhetoric that surrounds it, to the larger societal context within which it was conceived: as a response to the infringement of the lifeworld by the system, the Public Lab tools, their civic science approach, and the wide-ranging online and offline community of practice reveal an aspiration for a world that is more just, where people are not just able to understand their problems and solve them but also share those experiences with others around the globe and together knit stories that connect us with wider social and political contexts.

Through Public Lab, the examination of PIScR also reveals that the way to address this and make PIScR thrive is not through more science education, which is likely to be patronising, or increased transparency into the activities of scientists, which is likely to raise anxiety. Rather than focusing on questions symptomatic of the state about public ignorance, the public's perception of scientists, or examining the extent to which experts construct 'the public' (Stilgoe 2009), we need to move beyond and devote more attention to the relationships between people to demystify the boundaries between 'science' and 'non-science', 'experts' and 'non-experts' to reveal taken-for-granted constructions and perceptions of different ways of knowing, understanding, and doing. This would of course require a tremendous leap, as outlined by Powell and Colin (2008) in their study of more meaningful public engagement but it is necessary to enable people to determine their own future—in their own terms. That is, by getting out of their way so that they can develop their own creativity, develop trust in their abilities to question, to do and that what they do actually matters. This brings to question our role as academics and from within institutional organisations: people are already taking initiative solving their own problems, they are ingenious and resourceful and they know the power that knowledge can bring—there is much proof of this so where do we fit in? Our role in this social imaginary then becomes that of facilitators that give impetus to Publicly Initiated Scientific Research.

In reconsidering institutional and organisational approaches to participatory engagement in the production of scientific knowledge it is evident that much consideration needs to be given to the role of technologies, specially DIY and their situatedness within our cultures, which unavoidably are linked to the particular institutionalised patterns of power and authority within which they are conceived. Much work remains to be done to inform our practices as facilitators of systematic processes for the recognition and integration of multiple voices, ways of knowing, understanding, and doing; how do we conceive of exclusionary processes as less exclusionary, more porous, more engaging, and more friendly? How can we make PIScR practices like those of the Public Lab thrive while at the same time use them to help us reveal those unknowns that point to our potentials and unaddressed issues? It is clear at this point that a great deal more work is needed to conceive of processes for the acknowledgement and validation of DIY and grassroots practices with within current social arrangements.

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Part III
Collective Awareness, Learning and Decision Making

Introduction

Vittorio Loreto and Francesca Tria

A recent report from WHO (2014) states that in 2012 almost 7 million people died—one in eight of total global deaths as a result of air pollution exposure, confirming that air pollution is now the world's largest single environmental health risk (Burnett et al. 2014). If we look at the past policies we observe a growing debate about several environmental issues and an emerging consensus about the need for a reorganisation of our most impacting daily activities—energy consumption, transport, housing, etc.—towards a more efficient and sustainable development mode. Yet, there is generally not sufficient awareness to foster a rapid and effective change in behaviour and habits. The achievement of such a goal has been undermined by the difficulty of matching global/societal needs and individual needs (Hardin 1968; Ostrom 1990; Ostrom et al. 1994), but also by a lack of a complete understanding of the complex and nontrivial relationships among information, learning, awareness and behavioral change.

The professor of New Media Clay Shirky stated:

> A revolution doesn't happen when a society adopts new tools. It happens when society adopts new behaviours and most of that change I think is still in the future.

Here we take the challenge of reviewing different and complementary attempts of shading light into the complex relations between information exposure, both through broadcasted information and social networks, opinion formation and shift,

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and eventually changes in behaviour. A special emphasis is given in approaches that involve people active participation, for instance in local environmental monitoring, or through collective discussions aimed at proposing solutions to particular local environmental issues. Both theoretical and experimental findings ground in fact on scientific basis the illuminating saying:

> Tell me and I forget, teach me and I may remember, involve me and I learn.

In particular, Part III of the present book gives an overview of different studies and approaches that have been pursued with the aim of gaining a deeper insight into the mechanisms that drive people's understanding of environmental issues and enhance their awareness with the final goal of elucidating under which conditions it is possible to foster an effective change toward more virtuous behaviors.

In the first chapter of this part, Karen Akerlof, of the Center for Climate Change Communication of George Mason University, in her contribution entitled, *When Should Environmental Awareness Be a Policy Goal?*, reviews the policies adopted so far to engage citizens in the public debate about enhancing understanding and awareness on environmental problems. These policies are contrasted with more traditional "up-down" interventions, where people were exposed to focused information and guidelines. Difficulties in accessing the efficacy of such policies are highlighted and discussed, and general conclusions are drawn in favour of experiments were active participation of citizens, both in the public debate and in problem-solving activities, has been fostered.

The second chapter, by Gravino, Sîrbu, Becker, Servedio and Loreto, is entitled *Experimental Assessment of the Emergence of Awareness and Its Influence on Behavioral Changes: The EveryAware Lesson*. The authors are researchers who took part to the EveryAware project and reports about specific experiments, realized in the framework of that project, about learning processes and enhancing of awareness in volunteers engaged in environmental monitoring, specifically in noise pollution and air-quality case-studies. In addition this chapter highlights the opportunities that web-gaming (Caminiti et al. 2013; von Ahn and Dabbish 2004; von Ahn et al. 2006) and social computation are offering to the emergence of new forms of participation.

The third and final chapter, *Opinion Dynamics: Models, Extensions and External Effects*, by Sîrbu, Loreto, Servedio and Tria, reviews the theoretical approaches put forward to investigate the emergence of consensus and opinions in population of individuals, as modelled with the mathematical tools of the complex systems science. Different classes of opinion dynamics models are discussed, with a particular emphasis on the role that broadcasted information can have in driving consensus, or, on the contrary, in enhancing polarization or fragmentation in the set of opinions or beliefs of a population of individuals. This is a particularly interesting analysis since, as pointed out also in the chapter by Karen Akerlof, governmental pressure can have opposite effects if not suitably expressed. In particular, both from theoretical modelling, and from real-world examples, it emerges that information, in order to be effective, should carefully account for the current status (social, economical, cultural, etc.) of the public to be addressed.

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Chapter 15
When Should Environmental Awareness Be a Policy Goal?

Assessing the Conditions Under Which Raising Awareness Increases Environmental Sustainability and Societal Resilience

Karen Akerlof

15.1 Introduction

The ozone hole. Three Mile Island. Chernobyl. Bhopal. The BP oil spill. Fukushima. Disasters like these leave news headlines, images and emotions indelibly etched on our memories. They focus our attention, raise our awareness of the environmental risks that we face, and can lead to changes in policies on the heels of heightened public concern (Birkland 2006; Jasanoff 1994; Nohrstedt 2008; Ungar 2000). Our explanations for why people choose to take action to protect the environment, while others do not, sometimes follow a similar linear logic: People who engage in environmentally responsible behaviors have been exposed to salient information, whether through direct experiences or from other people or media sources, which increases their knowledge, changes their attitudes, and affects their subsequent decisions and actions.

We now know that these ideas about what creates change in people and political policies, although logical and at times true, are also overly simplistic (Birkland 1997; Kollmuss and Agyeman 2002). Intuitively, you might think that those who understand the basic science of climate change would be supportive of policies that reduce carbon emissions, yet those in the United States most likely to understand the mechanics of the greenhouse gas effect are also those who are most vociferously dismissive of these policies (Leiserowitz and Smith 2010). Or you might think that after radioactive fallout from the 1986 Chernobyl nuclear disaster rained across Sweden, the country would have been likely to respond to public pressure by accelerating its phase-out of nuclear power, and yet the disaster had no documented effect (Nohrstedt 2008).

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The everyday actions of individuals shape the physical, biological and social environments in which they live through the amount of water and energy they use, what they eat, which products or natural resources they use, what waste products they produce and how they dispose of it, and which governmental policies they support. The academic and practitioner literatures widely acknowledge that few, if any, direct effects on individuals' actions stem from information provision and raising awareness (Abrahamse et al. 2005; Hungerford and Volk 1990; Jackson 2005; McKenzie-Mohr and Smith 1999). It isn't hard to think of reasons for why that might be.

Along a river where our family and dog take frequent walks, shreds of plastic shopping bags hang from the branches of trees and bushes after being flushed downstream during high-water events following rainstorms. My awareness of the environmental consequences of plastic bags is high, as is my personal dislike of them, but if I go to the store unexpectedly without reusable bags, the default option provided at the check-out stand is a plastic sack. On those days, my behavior will likely not align with my level of knowledge or attitudes. The deficit is not information or motivation, but a lack of personal planning and external situational factors. As illustrated in Fig. 15.1, a sizeable number of individual, social and place-based factors can influence the final expression of behaviors in a population. Engrained habits, socioeconomic characteristics, perceived expectations for what

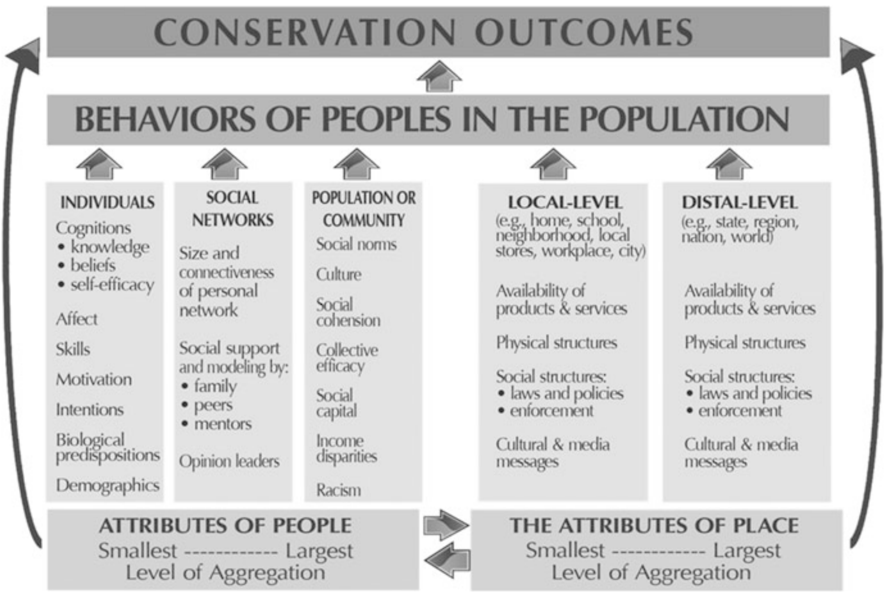

Fig. 15.1 Raising awareness of environmental issues can directly shape the knowledge and attitudes of individuals. However, many individual, collective and place-based factors influence population behaviors, as represented in this social ecological framework based on the "People and Places" model (Akerlof and Kennedy 2013; Maibach et al. 2007)

is considered socially desirable or normative behavior, and the structural design of the places where we live and work, all contribute to the behavioral equations of individuals, and writ large, of populations.

Nevertheless, all manner of governments and organizations continue to target awareness as a significant, if not primary, component of their communication campaigns and environmental education programs in pursuit of pro-environmental decisions and practices by the public. This approach is termed the "deficit" model, as it presumes public ignorance to be the root of environmental harms (Nisbet 2009). If the evidence for behavior change as a result of increased environmental awareness is weak, continued investment in these types of programs would seem to be unwarranted. Indeed, many an environmental communication campaign has been started by governments, only to see its funding cut not long afterwards (Akerlof and Maibach 2008; Gynther et al. 2012). Even so, this chapter, in describing our current understanding of the relations between knowledge, attitudes and behavior, suggests that under certain—but not all—conditions, raising public awareness as an end-goal in and of itself represents a highly necessary policy and programmatic goal for governments, one indeed required for liberal democracies.

15.2 State Motivation for Promoting Awareness and Environmentally Sensitive Behavior

Environmental degradation has long been a threat to human societies and the stability of political institutions, from the famed deforestation and soil erosion of Easter Island, and the resulting collapse of social order of that Polynesian culture, to the declines of ancient civilizations in Rome, Greece and Mesoamerica (Diamond 2005; Montgomery 2007; Redman 1999). For thousands of years states have suffered the costs of environmental declines, and at times sought to address them by influencing individuals' and organizations' attitudes and behaviors (if not always successfully), whether with a proposed ban on plowing to slow the erosion of the steep hillsides of Athens six centuries before the common era (Montgomery 2012), the game control laws of Kublai "The Great Khan" (Leopold 1987), or attempts at controlling air pollution from the burning of coal in Medieval England (Brimblecombe 2011). What *has* changed within recent decades is the scale of rising world populations, resource extraction, and pollution, and the evolution of new national and international environmental governance frameworks to restrain the resulting environmental damage (Frank et al. 2000).

In the last century, human populations have exploded, with corresponding impacts on their environments. In 500 B.C., at the height of Athens' power, approximately 100 million people populated the planet; by 1930 it was 2 billion, and today it is more than 7 billion (U.S. Census Bureau 2013). When measured in 2006, the area of land and water that the Earth's population of humanity needed to sustain itself was 40 % greater than the planet's capacity (Global Biodiversity Outlook 3, 2010). The second half of the twentieth century saw both the rapid advancement of public concern over the environment (Franzen 2003) and of domestic and international frameworks to address environmental degradation, such as national parks, intergovernmental environmental organizations, impact assessment laws, and national environmental agencies (Frank et al. 2000). Raising environmental awareness has been seen as a critical component of the success of these institutions, as embodied in the principles of the 1972 Stockholm Declaration on the Human Environment[1]:

> Education in environmental matters, for the younger generation as well as adults, giving due consideration to the underprivileged, is essential in order to broaden the basis for an enlightened opinion and responsible conduct by individuals, enterprises and communities in protecting and improving the environment in its full human dimension. It is also essential that mass media of communications avoid contributing to the deterioration of the environment, but, on the contrary, disseminates information of an educational nature on the need to project and improve the environment in order to enable man to develop in every respect. (Osmańczyk 2003, p. 2201)

The 1970s saw the growth of environmental education (Marsden 1997) and public communication programs in response to problems like littering, the energy crisis, and overconsumption of water resources (Campbell 2007; Geller et al. 2006; Huffman et al. 1995; Syme et al. 2000). By the beginning of the twenty-first century, realization of the dire nature of impending climate impacts, and political obstacles in achieving successful international treaties and national policies to limit carbon emissions, generated renewed interest in voluntary programs aimed at increasing the energy efficiency of individuals and households as a means of obtaining significant reductions in the production of greenhouse gases to as much as 40 % of national emissions (Dahlbom et al. 2009; Dietz et al. 2009; Vandenbergh et al. 2008). At the same time, governmental enthusiasm for low-cost, non-regulatory approaches based in behavioral economics surged across a wide span of policy areas—not just sustainability, but from public health to crime—in the United Kingdom and United States (Dolan et al. 2010, 2012). Thus, over the course of 40 years, interest in public awareness has grown as both a good in and of itself for the purpose of "enlightening opinion," and as an important precursor to population adoption of pro-environmental behaviors and policies. The roles of experts and the publics during this period is explored by Haklay in this volume.

Although the language of the UN's Stockholm Declaration on the Human Environment appears to conflate environmental education and public communication, and indeed both fields cite influencing awareness, attitudes and behaviors as a goal, the study and practice of these disciplines are distinguished by different approaches and informed by separate, at times overlapping, academic theories and paradigms (see Table 15.1). Environmental communication campaigns have become thought

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[1] Subsequent United Nations conventions on climate change and biodiversity further codified this commitment to educational and public awareness programs within international environmental governance (Convention on Biodiversity 1992; United Nations Framework Convention on Climate Change 1992).

Table 15.1 Comparison of communication and environmental education strategies (Monroe 2003)

Public communication campaigns	Environmental education
• Tailored messages to audiences • Providing information • Creating commitment • Utilizing incentives	• Significant life experiences • Environment-based education

of as synonymous with social marketing (Corner and Randall 2011; Monroe 2003), "a process that applies marketing principles and techniques to create, communicate, and deliver value in order to influence target audience behaviors that benefit society (public health, safety, the environment, and communities) as well as the target audience" (McKenzie-Mohr et al. 2011, p. 4).

Environmental educators, both academics and researchers, include behavioral change as one of the desired learning outcomes, but they also question the merits of this narrow definition and measurement of learning (Wals 2011). Under rapidly changing environmental conditions, and accompanying societal risks, Wals questions whether teaching students and citizens that there is a "best" behavior (or suite of behaviors) benefits societal adaptability in an age of post-normal science (2012). He claims that society is better served by developing individuals' agency to think, act and participate in the process of assessing environmental issues and their solutions, such as in the participatory processes described by Theunis et al. and Regalado in this volume. Funtowicz and Ravetz's (1993) theory of post-normal science holds that solutions to politically contested, high scientific uncertainty environmental problems rely on the democratization of decision-making processes with the participation of "extended peer communities" in order to generate "quality" solutions. For example, in the case of rising seas due to climate change, Funtowicz and Ravetz claimed "public agreement and participation, deriving essentially from value commitments, will be decisive for the assessment of risks and the setting of policy" (1993, p. 751). This model promotes critical thinking and civic participation in governmental decision-making instead of an instrumentalist approach to modifying specific behaviors in alignment with predefined government priorities.

Thus, three potential classifications of public policy goals in which environmental awareness may play a significant necessary role may be distinguished: (1) advancing behavioral change among individuals, and by default across populations; (2) facilitating democratic participation processes; and (3) promoting long-term community-level changes in education, values, and mores for more cooperative environmental decisions. Broadly, all three types of policy goals speak to the conditions under which groups successfully motivate individuals to cooperate, but with different, and yet necessarily complementary, methods. Importantly, they also imply that efforts to raise environmental awareness should not be judged solely on near-term population behavioral changes.

15.3 What is "Environmental Awareness"?

The celebration of Earth Day on April 22nd of every year by more than 192 countries and 22,000 organizations embodies one of the most widespread and long-running environmental awareness campaigns in history ("The history of Earth Day" n.d.; Rome 2014). Started by a United States senator from Wisconsin, the movement was born of a growing sense of concern over the human and environmental costs of toxic chemicals, water and air pollution, and the degradation of natural resources. On the first Earth Day in 1970, 20 million Americans rallied across the United States and launched an "environmental decade" of landmark legislation. Earth Day teach-ins have continued every April over the past four decades.

The complex dynamics of Earth Day events—a combination of education, mass media, political advocacy, and collective action—illustrate the difficulties of explaining what it means to raise environmental awareness, even though it is a frequently stated goal of communication, education and outreach campaigns. In the 1970s, awareness was identified as one of the primary objectives for the newly emergent field of environmental education as the conditions under which "social groups and individuals acquire an awareness and sensitivity to the total environment and its allied problems" (UNESCO and UNEP 1978). By this definition, awareness encompasses the concept of "sensitivity," feelings of empathy or concern for the environment derived from formative experiences in the natural world (Chawla 1998; Hungerford and Volk 1990; Tanner 1980).

In contrast, pro-environmental communication campaigns are typically divorced from direct experiences of nature. They focus instead on raising awareness by conveying information using mediated channels like print ads, radio, television, social media, websites or public opinion leaders. Awareness messages are comprised of "simple content that informs people what to do, specifies who should do it, and provides cues about when and where it should be done" (Atkin and Rice 2012, p. 534). These types of campaigns evoke social influence processes described by Sirbu et al. in their descriptions of public opinion dynamics in this volume.

Given the differences in the ways that educators and communicators view awareness, social scientists not surprisingly also define it differently, sometimes even within the same discipline. Geographers have used the term awareness to mean observation of physical conditions, such as weather and climate variables (Ruddell et al. 2012). Environmental education and psychology researchers have described awareness as incorporating both elements of knowledge and concern about the environment (Grob 1995; Kollmuss and Agyeman 2002), including an understanding that our actions cause environmental problems (De Groot and Steg 2009; Nordlund and Garvill 2003), and that environmental problems pose a threat to items of value (Stern 2000). Risk psychologists do not use the term "awareness" at all, but study the same types of phenomenon under the umbrella of "risk perception," in which individuals make judgments about "events, situations or activities that could lead to negative consequences" for things of value, including human beings and the environment (Renn 2008, p. 98). Risk perception, too, is based on two components: information about risk gained either through recognition of physical indicators or through social communication; and a judgment about a risk's severity, likelihood or acceptability. *Thus, a broad definition of "environmental awareness" could be said to encompass those variables which fit into the following two categories: (1) possessing information about environmental conditions, and the causes and consequences of changes to environmental conditions; and (2), an individual's evaluation of those conditions.*

15.4 Raising Awareness as a Policy Instrument for Behavior Change

Early linear models of behavior change sometimes equated environmental awareness with attitudes, and placed awareness and attitudes as the critical intervening variables between knowledge and behavior (Hungerford and Volk 1990), which has made awareness an appealing goal in the pursuit of motivating individual behavior change, and multiplied many times over, population-level change (Fig. 15.2). Evert Vedung (2011) theorized that policy instruments can be reduced to three broad categories: carrots, also known as subsidies; sticks, or regulations; and sermons, such as information campaigns. His typology is cast within the context of governmental tools to influence pro-social behavioral change, particularly over relatively short decision-making time frames.

In this context, raising public awareness is juxtaposed against tax credits or regulations in the government's policy toolkit for the protection of environmental goods, such as air and water quality. Instrumentalist policies attempt to motivate individuals by appealing to their short-term interests in avoiding losses or acquiring gains (Tyler 2013). Communication "sermons" also frequently fall into this category. For example, energy messages typically emphasize the cost savings to household utility bills. In a series of public service advertisements developed by the Advertising Council in 2011 for the U.S. Department of Energy, Americans are told not just that saving energy saves them money, but that it saves "date night" and "movie night" (Restuccia 2011). One of the ads shows a turkey being cooked by incandescent light bulbs: "Traditional light bulbs actually generate nine times more heat than light. Switch to EnergyStar light bulbs and you'll realize just how much cash you were really burning through."

One of the contributions of psychology has been to illuminate that pro-social and pro-environmental motivations—including attitudes, values, identity, fairness, and trust—can be as strong, or stronger, than self-interest in obtaining public cooperation to achieve collective goals (Stern 2000; Tyler 2013). Social motivation may be particularly important for pro-environmental behaviors, which are often associated with little private gain by individuals, but great benefits for the social groups to which they belong. Garrett Hardin's (1968) "tragedy of the commons" illustrated the problem of managing common resources when individuals are not incentivized by

Fig. 15.2 Many communication campaigns, such as these by the U.S. Dept. of Energy, are instrumentalist in that they appeal to an individual's material self-interest

material self-interest to conserve them. More recent evidence indicates that in some cases, groups do successfully manage common pool resources, especially when their social values and mores support trust, reciprocity, and wise use (Ostrom et al. 1999).

Campaigns to motivate individual behaviors may also target pro-social motivations. For example, a climate change poster from the 2014 "Climate Victory" campaign (Fig. 15.3) promotes rooftop solar energy sources based on their community benefits, including local energy and stronger communities ("'Climate Victory' campaign turns back the clock on clean energy battles," 2014). The efficacy of instrumentalist policies that focus on individual's short-term self-interest is widely over-estimated, according to Tyler, who suggests that policies that promote voluntary cooperation with groups based on social motivations are often more fruitful (2012).

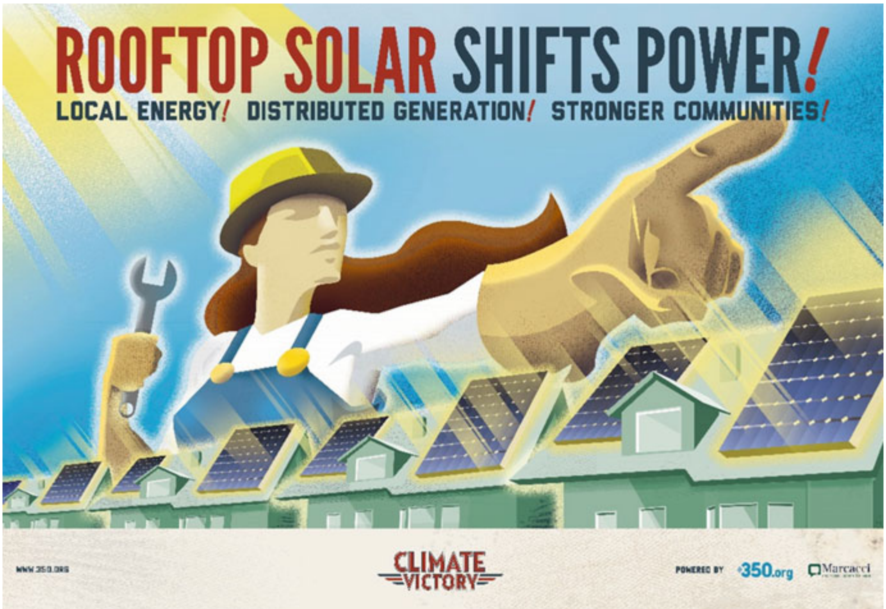

Fig. 15.3 This "Climate Victory" campaign poster from Creative Action Network, 350.org, Marcacci Communications and Green Patriot Posters appeals to social motivations by emphasizing the community benefits of solar power

15.5 When Raising Awareness of Environmental Risks Backfires

As governments seek to reduce their greenhouse gas emissions to reduce the likelihood that climate change will cause "severe, pervasive and irreversible impacts for people and ecosystems" (IPCC 2014), they have incorporated awareness and behavior-change campaigns into their policy toolkits. The United Kingdom has one of the longest histories of governmental use of campaigns to raise public awareness to reduce the greenhouse gas emissions that cause climate change, and also funded a campaign that has become known as one of the most infamous examples of the ways in which these efforts can backfire.

Prior to the signing of the Kyoto Protocol in December 1997, the UK's deputy prime minister requested a campaign to promote individuals' environmentally responsible actions. "Are You Doing Your Bit?" launched in March 1998 and ran through 2002 (Akerlof and Maibach 2008). The campaign sought to make the environment a mainstream issue, promote awareness of pro-environmental actions, create a strong link between climate change and individual actions, and generate a strong brand identity. Yet by March 2000 members of Parliament were unhappy with the campaign. A House of Commons report stated the effort was "half-hearted and ill-focused," but concluded with support for follow-on efforts aiming at long-term, specific behavioral changes, instead of general public awareness.

"Act on CO_2" subsequently launched in 2007 as an overarching brand for initiatives run by multiple governmental departments (Hards and Wentworth 2010). The campaign combined information provision, including a personal carbon footprint calculator, with persuasive advertising that ramped up in 2009 with a series of hard-hitting television, press and billboard ads by advertising agency AMV BBDO and cost £6 million (more than $9 million U.S. dollars). The goal was to demonstrate to the public that climate change will affect them; surveys had shown that more than half of citizens did not believe that to be the case (Sweney 2009). The ads used nursery rhymes to convey the effects of climate change on children, centered around a television ad titled "Bedtime Story." The ad showed a father reading a story to his young daughter in which a cloud of CO_2 shaped as a monster causes a town to flood, leaving people clinging to the roofs of buildings and a dog sinking underwater. Almost 1000 complaints were lodged against the ads between October 2009 and February 2010 to the Advertising Standards Authority (ASA) citing factual inaccuracies and overly disturbing content (Advertising Standards Authority 2010). Another 537 complaints to Ofcom, the UK's communications regulatory body, claimed that the ads were political (Ofcom 2010).

Organizations decried the fear tactics used in the ads (Gillespie 2010; Hards and Wentworth 2010), but the Department of Energy and Climate Change, which launched the campaign, was cleared of all but two claims by both ASA and Ofcom. Two of the press ads (Figs. 15.4 and 15.5) were deemed to have made overstated claims as to the effects of climate change on extreme weather and were banned (Advertising Standards Authority 2010). However, Ofcom concluded that the ads served "to raise viewers' awareness of the issues of climate change" and hence qualified as public service announcements (Ofcom 2010). The campaign was dropped, and subsequent government reports have been critical, calling the effort an information-only approach lacking in a complementary set of interventions that would address barriers to behavior change (Science and Technology Select Committee 2011).

15.6 Breaking Down Awareness into Its Constituent Parts

If environmental awareness may be defined as possessing information about environmental conditions, the causes and consequences of changes to environmental conditions, and an individual's evaluation of those conditions, then the components of awareness—here defined as knowledge and attitudes—may be examined. Indeed, early psychological models postulated that knowledge and attitudes were the two primary predictors of behavior (Kollmuss and Agyeman 2002) (Fig. 15.6). Information about environmental conditions, and the causes and consequences of environmental change, can be described as "**knowledge**." This knowledge can be acquired from a number of sources, such as direct experience, or social transmission

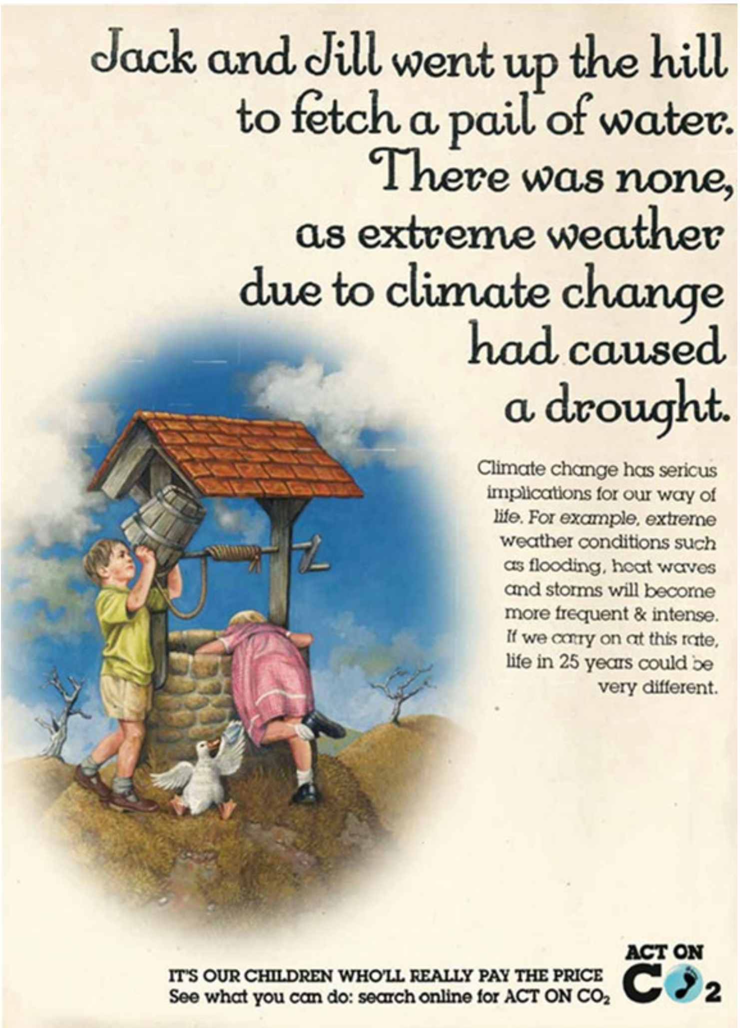

Fig. 15.4 Two ads by the UK's Department for Energy and Climate were found to have overstated the impacts of climate change on extreme weather by the Advertising Standards Agency. This first ad highlights drought; see also Fig. 15.5. Public domain images

from sources such as the media. Knowledge of environmental issues involves a potentially wide-ranging scope of information, from broadly understanding the relations between physical, biological and social systems to knowing which specific actions are beneficial or harmful for the environment and society (Clayton and Myers 2009). Knowledge is typically measured by asking people whether certain statements are true or false in an assessment of whether the information they hold is accurate (Ajzen et al. 2011). Knowledge is distinct both from the quantity of

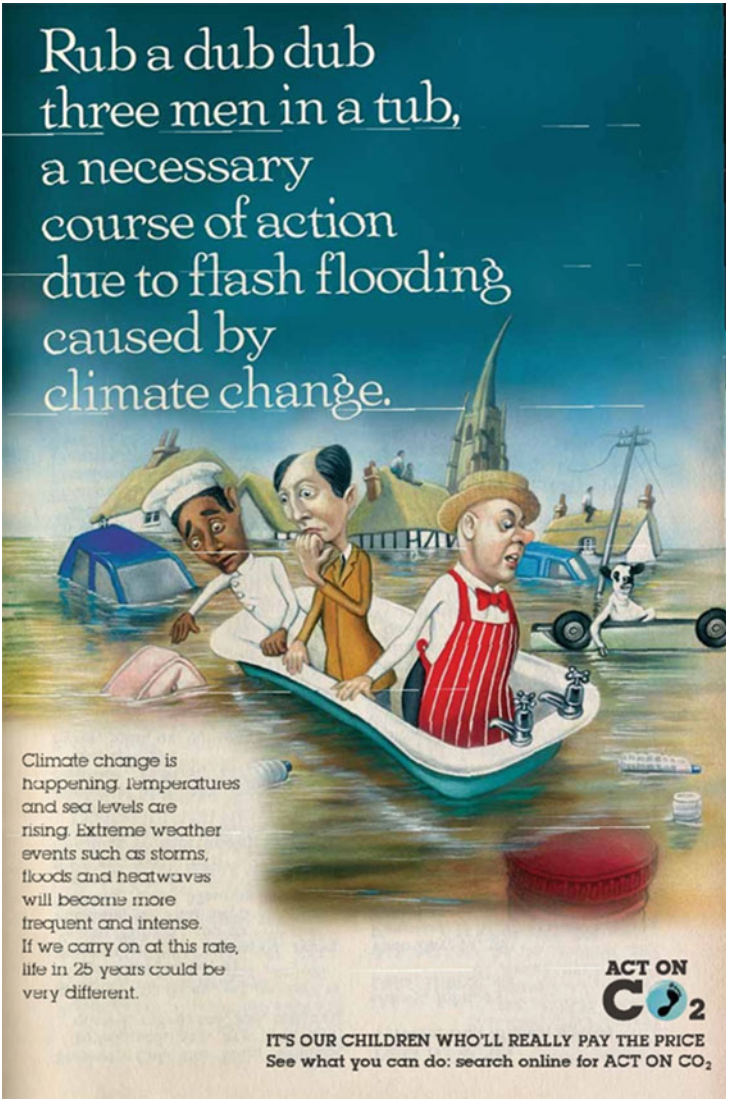

Fig. 15.5 A second ad by the UK's Department for Energy and Climate that was found to have overstated the impacts of climate change on extreme weather focused on flood events. Public domain images

information that an individual holds about a topic, and also an individual's beliefs, which may or may not be factually correct.

Individuals' evaluations of environmental conditions may be described as "**attitudes**," as in Visser and Holbrook (2012, p. 21), "evaluations of people, places, and things in our environment," but they are connected to a host of other

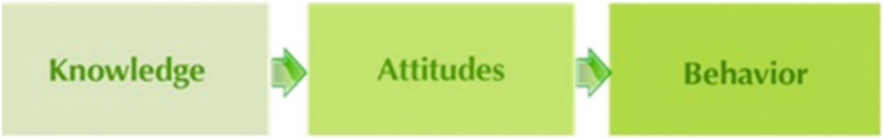

Fig. 15.6 Early linear behavioral models placed knowledge and attitudes as the two most important predictive factors (Akerlof and Kennedy 2013)

individual-level psychological variables as well. Heberlein (2012, p. 32) describes attitudes as “based on values and built on beliefs, some of which are knowledge and some of which contain an emotional component.” The most important aspect of attitudes in relation to behavior change is the extent to which they are strongly or weakly held. Strongly held attitudes can be powerful. They can influence our perceptions, what we believe, and what we actually do.

Psychological models place knowledge and attitudes in central roles predicting behavior, but whether they typically have any effect, or whether the communication and education efforts that create interventions around them do as well, is questionable. I will next review both the evidence for the influence of knowledge and attitudes on behavior, and related criticisms.

15.7 Knowledge

Objective knowledge of the world around us comes from two sources: direct and indirect experience. When individuals are able to directly detect risk signals in their environment these signals are particularly strong in influencing attitudes and behavior, likely because of their rich detail (Wu and Shaffer 1987), vividness and salience, and the ease and speed by which this type of information is processed (Epstein 1994). Yet individuals’ experiences of their physical and social worlds are inextricably intertwined. Mediated experiences like photographs, video, or simulations may approximate the effects of direct experience (Ahn et al. 2014; Uzunboylu et al. 2009), such as the web games described by Servedio et al. and Gravino et al. in this volume. Direct experiences are filtered by sociocultural lenses which guide which signals in the environment to which people pay attention, and how they are interpreted (Goebbert et al. 2012; Marquart-Pyatt et al. 2014; Myers et al. 2013; Ruddell et al. 2012). Finally, knowledge of environmental conditions is socially mediated through formal and informal education, mass media, and interpersonal communication. These latter pathways are ever more important as the time people spend outside declines in some parts of the world; outdoor recreation has decreased since the 1980s in the United States and Japan as consumption of electronic media has risen (Pergams and Zaradic 2008).[2]

Strength of Links to Behavior Objective knowledge influences behavior in part by increasing pro-environmental attitudes. In a meta-analysis of 46 studies conducted since 1995, Bamberg and Möser (2007) found that increased problem awareness/knowledge correlates with heightened pro-environmental attitudes ($r = 0.30$) and behavior ($r = 0.22$), and operates indirectly on attitudes and behavior through social norms, internal attribution, and feelings of guilt. An earlier meta-analysis (Hines et al. 1987) also found a similar level of association between knowledge of environmental issues and behavior ($r = 0.30$). The correlation was stronger when actual behaviors were measured, as opposed to self-reports ($r = 0.37$ vs. $r = 0.29$). These correlations suggest a small-to-medium effect of knowledge on behavior; a correlation of 0.30 means that that predictor variable accounts for 9 % of the variance of the outcome variable.[3]

Related Constructs Objective knowledge describes the amount of information that an individual holds in memory. In contrast, perceived knowledge describes an individual's subjective perception of how much knowledge he or she has about a particular subject (Visser and Holbrook 2012). Counter-intuitively, perceived knowledge is only weakly correlated with levels of objective knowledge. Conditions such as social context, length of time considering a topic, and considered importance all can influence perceived knowledge apart from measured levels of objective knowledge. According to Visser and Holbrook's review of the determinants of attitudinal certainty, objective knowledge increases attitudinal certainty by way of perceived knowledge and the complexity of an individual's knowledge structure, i.e., the number of dimensions that an individual can identify within the same amount of information.

Perceiving oneself to be knowledgeable on a topic is one pathway by which information influences behavior; beliefs are another. Ajzen and colleagues (2011) claim that being well-informed by itself has no particular effect on behavior, unless that information is incorporated into an individual's belief system. Beliefs about an action's consequences, the expectations and actions of others, and factors that influence control over the action—irrespective of whether they are factually right or wrong—shape a constellation of attitudes about the behavior, social norms and perceived behavioral control that then predict behavioral outcomes. Notably, many

[2]Changes in the amount of time that children spend with electronic media, as opposed to playing outdoors, has sparked particular concern (Louv 2008). Pergams and Zaradic caution that the United States may be experiencing a decline in appreciation of nature, or biophilia, as a direct result of "videophilia" (2006).

[3]A Pearson's correlation (r) is a numerical measure of the strength of a relationship between two variables with a range of 0 (no association) to 1 (an extremely strong). Cohen's rule of thumb is that a correlation of 0.10 as a small effect, 0.30 as a medium effect, and 0.50 as a large effect (Cohen 1992).

psychological models of behavior start with beliefs instead of knowledge (Jackson 2005).

Criticisms One of the criticisms of knowledge and its influence on attitudes and behavior is that it is frequently measured incorrectly. Topic knowledge is assessed in surveys using sets of factual assertions that respondents are asked to check as true or false. Ajzen and colleagues (2011) argue that this technique invariably captures attitudes instead of knowledge because respondents guess at the answers, using their attitudes toward the topic as a guide. Whether a respondent is ranked as "knowledgeable" by the scale depends on the ratio of factual statements in the scale that are consistent with their attitudes. When scales were balanced with a ratio of items that did not favor attitudinally based guesses, the authors found no correlation between environmental knowledge and energy conservation.

A second criticism of objective knowledge as an important construct for the purposes of public policy is whether measuring levels of public understanding of science is a misleading representation both of science and the relationship of lay audiences to science. Within the field of public understanding of science, researchers have long found that understanding of science and general attitudes toward science are weakly associated, including for specific topics such as climate change (Kahan et al. 2012; Ziman 1991). Critics of measuring public knowledge of science and contrasting it with expert knowledge (a "cognitive deficit" model) have submitted that scientific knowledge is equally a social construction of scientists and their institutions as for the lay public (Michael 1996; Wynne 1991). If there is no consensus among scientists as to the definition of scientific knowledge in any context, as these social scientists claim, this renders the comparison between knowledge structures of the lay public and experts problematic. As noted by Ziman at an April 1990 conference in London titled "Policies and Publics for Science and Technology":

> … "Science" is not a well-bounded, coherent thing, capable of being more or less "understood." This finding is not in any sense a subversive attack on the marvelous and immense body of work produced by scientists, engineers, physicians, technologists, and other researchers. Instead, it is a reminder that what counts as science is sometimes defined very differently by different people—or even by the same people under different circumstances (Ziman 1991, p. 100).

15.8 Attitudes

When individuals are exposed to information or experiences, they form either positive or negative attitudes about a specific object, issue or behavior, illustrated by the first example in this chapter: "I dislike plastic bags." Measures of attitudes pervade both public surveys and social science research. By one count, at least 18 different environmental attitude scales have been created since the 1970s (Gifford 2014), including one of the most well-known, the New Environmental Paradigm

Table 15.2 The relations between values, beliefs and attitudes (Bem 1970; Heberlein 2012)

Attitude	I dislike plastic bags	
Evaluative belief	Bags that do not pollute the environment are better	
Beliefs	Reusable bags are less likely to be thrown out and create waste	Plastic bags result in environmental harms
Value	Universalism: Protection of the welfare of people and nature (Schwartz 1994)	

Scale (Dunlap 2008). Pinning down environmental attitudes has also been elusive. In his book "Navigating Environmental Attitudes," Heberlein wrote:

> When I once used the ghost metaphor to describe attitudes, one of my cynical and savvy environmental colleagues replied, "Well, I don't believe in ghosts either . . . but I am afraid of them." He was right. If you are trying to solve environmental problems, you better be afraid of attitudes. Even though they are difficult to pin down, and even harder to change, attitudes are fundamental to environmental solutions. (Heberlein 2012, p. 5)

Strongly held attitudes are enduring because they are a combination of emotion and beliefs that are built upon the foundation of an individual's values with implications for his or her behavior (Table 15.2). Traditionally, beliefs have been thought of as the cognitive portion of this Gordian knot; emotion as the affective driver; and behavior as the stated intent or overt response (Breckler 1984; Gifford and Sussman 2012). The attitude-behavior link is strengthened by attitudes obtained through direct experiences, repeated expression, increased certainty of being "correct," and exposure to information biased toward action: qualities that increase their ease of recall and the length of time they are held (Glasman and Albarracín 2006). The directional link between attitudes and behavior can reverse at times, however. Notably, attitudes can also change when people realize that their behaviors are not aligned with their attitudes, which causes cognitive dissonance and motivates behavioral, attitudinal or belief change (Festinger 1962).

The proposed link between attitudes and behavior assumes that individuals attempt to keep their attitudes and behaviors consistent. In a practical sense, this means that when studies are designed, researchers make assumptions about which attitudes and behaviors should be connected in the minds of their participants. For some behaviors, these links might be clear, but others less so. Let's use the example of attitudes about climate change and behaviors that influence greenhouse gas emissions. Lessening air pollution from power plants has clear outcomes for air quality and climate change (power plants were featured in the movie posters for Al Gore's "An Inconvenient Truth"). Eating hamburgers, however, is not as easily understood in terms of its effects on greenhouse gas emissions (de Boer et al. 2013). As a result, all other contextual factors aside, consistency in attitudes toward climate change and behaviors about energy use would be expected to be greater than with eating red meat.

Ajzen and Fishbein (1977) postulated that both attitudes and behaviors potentially have four elements: an action, a target, the context of the action, and the time frame. They argue that measurements of attitudes and behaviors will only be highly correlated if they are equally specific, especially for the action and target. For example, my attitude toward bringing reusable bags to the grocery store for the family's Saturday shopping trip should be highly correlated with a measurement of that observed behavior on a typical weekend shopping trip. In contrast, a general measure of my attitudes toward plastic sacks would not be expected to be as strongly correlated with observation of my use of reusable bags during a Christmas shopping trip at a mall—a context in which bringing your own bags is still outside social norms in the United States.

Strengths of Links to Behavior Positive attitudes can be a necessary precondition for adoption of pro-environmental behaviors, but are not always sufficient, especially if they are not specified at the same level of the behavior, or if the social or physical context poses barriers (Heberlein 2012). One meta-analysis found much stronger association between attitudes and behavior than between knowledge and behavior ($r = 0.54$ vs. $r = 0.22$) (Bamberg and Möser 2007), whereas another found a smaller difference ($r = 0.39$ vs. $r = 0.30$) (Hines et al. 1987). Indeed, the relations between attitudes and behaviors can be highly variable (Glasman and Albarracín 2006), and in many studies has been so weak as to be labeled a "gap" (Kollmuss and Agyeman 2002).

Related Constructs Like environmental awareness, attitudes have been defined differently over time by scholars (Breckler and Wiggins 1989), and in common parlance. Environmental attitudes are sometimes conflated with environmental concern (Gifford and Sussman 2012; Van Liere and Dunlap 1981). Concern can also be defined as an emotional response to environmental issues that is related, but distinct (Schultz et al. 2004). In a strict sense, attitudes are an evaluative judgment of an object (Eagly and Chaiken 1993), but when researchers refer to "environmental attitudes" writ large, they can be referring to its three components: affect (emotion), cognition (thoughts and evaluation), and conation (desire or volition to act). For example, Schultz and colleagues used both a limited definition of attitudes based on that of Eagly and Chaiken, and a broader definition of environmental attitudes incorporating all three components: "The construct of environmental attitudes refers to the collection of beliefs, affect, and behavioural intentions a person holds regarding environmentally related activities or issues" (Schultz et al. 2004, p. 31). This usage describes a hierarchical model in which beliefs, affect and behavioral intent are first-order factors, and attitudes are a second-level factor representing the larger construct (Ajzen 2005).

Criticisms Some social scientists have questioned whether attitudes, like ghosts, are real or figments of researchers' imaginations in their quest to understand human cognition and behavior (Kraus 1995). Wicker (1969, p. 75) assessed the link between attitudes and behaviors as follows: "The present review provides little evidence to support the postulated existence of stable, underlying attitudes within the individual which influence both his verbal expressions and his actions." The question is whether surveys, which measure verbalized responses, typically with paper or online questionnaires, can possibly capture the complexity of individual factors of significance in behavior, and as a result, factors of significance for social policy programs. “Can we assume that if we are attempting to alter behavior through a training program, an educational campaign, or some sort of information intervention, a measured change in attitude in the ‘right’ direction results in a change in behavior?” (Deutscher 1965, pp. 249–250).

Despite these concerns, the assumption that attitudes are important in determining behavior has largely remained intact over the decades. Researchers have sought to explain the weak correlation between attitudes and behavior in two ways: (1) methodological problems of measurement; and (2) moderator variables (Kraus 1995). The most well-known of the methodological explanations for low attitude-behavior consistency is the lack of specificity of attitudinal and behavioral measures (Ajzen and Fishbein 1977). If each behavior has a distinct set of predictors, including attitudes, general attitudes may have little relevance. This does not mean, however, that understanding broad attitudes is irrelevant; evidence suggests both general and specific attitudes are predictive of behavior (Gifford and Sussman 2012). Perhaps more worrisome is the common technique of measuring self-reported behavior and behavioral intent instead of observed behavior in many survey-based studies. Kormos and Gifford (2014) found a correlation of 0.46 in a meta-analysis of studies comparing self-report data to behavior, which they described as “conventionally large, but functionally small.”

Even if attitudinal and behavioral variables are perfectly measured, the question remains whether behavioral models are fully specified. Do they include all the individual and situational factors that either moderate or interact with attitudes to determine which types of people, in which situations, choose to act (Kraus 1995)? If models are unique to specific behaviors and contexts, without a grand unifying theory, the value of psychological science for understanding, predicting, and shaping behavior declines significantly.

15.9 Knowledge and Attitudes in Behavioral Models

One of the more complex questions for practitioners and academics in predicting behavior is how combinations of factors, such as those described in Maibach and colleagues’ People and Places model (2007), work together. Although knowledge gain and attitude change are often necessary conditions for behavioral adoption, other factors also play a role in the pathway to action. Psychological models describe the presumed causal paths between these factors and their relative strengths in predicting behavioral intent, or enactment. Arguably the most influential of the theories about how these factors relate to each other, the Theory of Planned Behavior (TPB), incorporates attitudes, perceived social norms, and perceived behavioral control (Ajzen 1991; Ajzen and Madden 1986). When these three factors combine favorably, they promote an individual’s “intention” to take an action, which can be facilitated by environmental conditions or hindered by lack of opportunity. A review of 30 papers applying the theoretical framework in interventions reported small to medium effects, and behavioral changes in two-thirds of the cases where it could be assessed (Hardeman et al. 2002); a larger review (185 papers) found these factors predicted about a quarter of the variance in behavior across samples (Armitage and Conner 2001).

The fundamental differences in motivations between actions taken to protect *collective* environmental resources—like clean water and air, and species diversity—and improving one's own *individual* well-being (per much of the behavioral change literature), have drawn attention to a potentially larger role for personal morality in shaping pro-environmental behaviors. A framework developed explicitly for pro-environmental behaviors, the Value-Belief-Norm Theory (VBN), posits that the deep, underlying values we hold about ourselves, others and the environment serve as the wellspring for action (Stern 2000). Indeed, a test of the model using support for energy policies that reduce carbon dioxide emissions found that values and beliefs about human-environmental relationships, in turn, impact specific beliefs and personal norms about behaviors, and finally, policy acceptability (Steg et al. 2005). These two theories (TPB and VBN) represent not so much competing possible behavioral change pathways as different areas of emphasis, which may be complementary to the extent that values and beliefs also precipitate favorable or unfavorable attitudes toward taking action (Gifford et al. 2011).

In assessing where to target interventions among the wide range of variables in these models, different emphases may be more appropriate on different operational timescales. In conservation psychology, researchers have suggested distinguishing between behavioral change goals with shorter timeframes—e.g. targeted efforts, frequently using marketing-based approaches on factors such as environmental contexts, social norms and attitudes—from those that are longer term, such as changes to underlying personal values and morals using education and formative environmental experiences (Monroe 2003).

15.10 Do We Need Awareness to Achieve Behavior Change?

"Human rational behavior … is shaped by a scissors whose two blades are the structure of task environments and the computational capabilities of the actor," wrote economic sciences Nobel laureate Herbert Simon (1990, p. 7). In a review of 41 governmental programs focused on behavioral changes in regards to energy in European Union nations, 37 of the programs addressed awareness, knowledge and attitudes, but only 17 included possible external factors, such as financial resources (Gynther et al. 2012). By the turn of the century, social scientists urged governments to consider behavior change programs that circumvent people's slower and more easily overloaded cognitive processing of information and instead rely on their use of environmental cues and decision-making shortcuts, or heuristics, largely unconsciously (Thaler et al. 2010; Thaler and Sunstein 2008, 2003). These "nudges" do not directly limit the choices of citizens or target monetary incentives but instead restructure the way that choices are delivered, and shape physical and social environments to promote preferred actions instead of prohibiting others.

The behavioral science foundation for these types of "soft policy" approaches is an understanding that the cognitive processing of information assumed by traditional models of "rational" human decision-making (termed "Type 2") does not account for the majority of decisions people make every day because it is too effortful, time-intensive, and energetically costly (Kahneman 2003; Stanovich and West 2000; Vohs et al. 2008). In contrast, "Type 1" processing, which automatically and swiftly processes stimuli, registering information from the environment in terms of frequencies and associations, is part of our wider evolutionary heritage shared with other species (Sloman 1996), at times tagging it with overtones of negative or positive affect, and shaping our behavior in ways that we may not even recognize (Wansink and Sobal 2007). The biological advantage of humans' ability to automatically respond to environmental cues is the weak demand on our cognitive capabilities. Making choices exacts mental and physical costs (Vohs et al. 2008). Individuals rely on external cues to reduce the quantity of information they consider, and the number of conscious decisions that must be made (Todd and Gigerenzer 2012).

Financial stress reduces cognitive abilities, including the ability to make decisions (Carvalho et al. 2014; Mani et al. 2013). In these cases, governmental awareness efforts may cause more harm than good, especially if they attract attention away from more important individual goals, such as financial decisions. Facilitating pro-social behaviors without further taxing the attentional limits of particularly vulnerable members of society may represent a more rational policy goal. However, in these situations and others, uses of "nudges" raise questions as to the ethics of manipulating people without their knowledge or consent (Saghai 2013; Sunstein 2014).

15.11 Raising Awareness to Increase Education and Public Participation in Decision-Making

Tension between the goals of democratic societies to reflect the "vox populi" and to temper the will of the people by reasoned, well-informed deliberation has a long history (Fishkin 2009). This stems from the recognition that public opinion is often not well-informed or well-considered, and that indeed on many issues, the public may have no opinion at all. The earliest experiments about how to resolve this tension in democratic societies were conducted by the Athenians, who on a yearly basis drew 500 names from a list of willing citizen participants to serve as a deliberative body. The purpose of formal education is in part to inform public engagement in the civic affairs of democracies.

Public engagement has increasingly been recognized as a vital component of environmental assessment and decision-making over the past 40 years in many nations and intergovernmental organizations. Public environmental awareness—knowledge and attitudes—is needed for citizens to make decisions that affect themselves and their families and to participate in these democratic processes. The requirements for public notice and comment embodied in the National Environmental Policy Act of 1970 (NEPA) were incorporated into the majority of subsequent federal laws and statutes, and recommended for state and local adoption (National Research Council 2008). NEPA has been emulated by more than 80 national governments and international regional institutions such as the World Bank and European Union (Andrews 2006, p. 285).

The dominant arguments in favor of public involvement are that it increases the quality and legitimacy of decisions, and develops the capacity of both governmental officials and citizens (National Research Council 2008). A meta-analysis of 239 case studies of public participation by Beierle and Cayford (2002) supported these conclusions. The majority met four out of five social goals defined as criteria for success: incorporating public values into decisions, improving the quality of decisions, resolving conflict among competing interests, and educating and informing the public. Slightly less than half of the cases also succeeded in building trust in institutions, the fifth criterion.

Public participation also has disadvantages, including perhaps more enthusiasm for the idea in theory than actual practice. Arnstein (1969) described citizen participation as "a little bit like eating spinach: no one is against it in principle because it is good for you." Irvin and Stansbury (2004) concisely summarized the advantages and disadvantages for both citizen participants and government officials as a function of the decision-making process and outcomes. For government officials, cost, time, and potential loss of control of the policy debate pose large downsides. The public faces fewer losses even under sub-optimal participatory conditions, primarily believing that it may be a waste of their time.

In contrast to formal and informal education programs at schools, museums, zoos or parks in which educators focus on learning processes, public deliberative forums are community events with both cognitive and social elements (Gastil 2008). One of the central characteristics of deliberative events is the small-group discussion that participants engage in during the deliberative session. Typically, participants are selected randomly into the small groups to ensure the representation of a diversity of viewpoints (Fishkin and Luskin 2005). Because participants spend most of their time in these small groups, the groups become the defining experience of the deliberative session, and the interactions with others from within the community—hearing and giving arguments for one or another policy option—are believed to stimulate knowledge acquisition and changes in policy preferences (Barabas 2004).

Although critics of deliberative forums accuse them of being disconnected from actual decision-making, unrepresentative, and so infrequent as to be irrelevant, the list of benefits accorded to collective forms of deliberation is long, and similar to those attributed to public participation generally (Carpini et al. 2004). It includes increases in citizen engagement in public affairs; increases in tolerance of other viewpoints; gains in individuals' understanding of their own preferences and abilities for argumentation; realization of social interdependence; faith in democratic processes; more considered and informed political decisions; and growth of social capital.

Deliberative fora have been shown to increase participants' factual information and the empirical basis for their policy preferences, change opinions, and change voting intentions (Fishkin and Luskin 2005). The representative nature of the sample of citizens who participate in the deliberations legitimatizes their advisory recommendations to policymakers as "the voice of the people." The events have gathered together citizens from counties (Allegheny County, Pennsylvania; Program for Deliberative Democracy, http://hss.cmu.edu/pdd/index.html), states and nations (California, the United States, China, Japan; Center for Deliberative Democracy, http://cdd.stanford.edu/), and the globe (World Wide Views on Global Warming, http://www.wwviews.org/). In case studies from the many deliberative polls conducted both nationally and internationally, communities have adopted policy decisions based on the results of the events (Fig. 15.7) (Fishkin 2009).

Fig. 15.7 A facilitator leads a group discussion on the science of rising sea levels and policy options with residents of Anne Arundel County, Maryland. *Photo courtesy Bob Baker*

15.12 Awareness of Local Sea-Level Rise Rises During Deliberation

As an example of the role of environmental awareness in public participatory discourses and decision-making, the author and colleagues on the Future Coast/CASI project investigated how individuals' knowledge, attitudes and policy preferences might change over the course of a deliberative community session (Akerlof et al. 2013). Residents carried on discussions in small groups with facilitators regarding the science and policy implications of sea-level rise to their county, including detailed online information about coastal flooding and inundation risks at the household level. By developing a collection of multi-media resources online, the research team sought to create a widely accessible freestanding platform to inform public discussion of climate change adaptation choices.

This study demonstrated that coastal flooding and other effects from the rising waters of the Chesapeake Bay are of concern to Anne Arundel County residents, but that citizens were uncertain of the dimensions of the problem in terms of its risks, response options, and time frames. Moreover, citizens' risk perceptions about the effects of sea-level rise on the county were influenced by preferences for societal "ways of life" or "worldviews" that closely align with political ideology (Kahan 2012). The deliberative community event, termed a "Citizens' Discussion," contributed to residents' learning about these issues, in terms of their knowledge, risk perceptions, and policy preferences. Significantly, it also increased participants' sense of political self-efficacy. This suggests the utility of community discussions on difficult long-term policy issues not only in facilitating public consideration, but in increasing citizens' beliefs in their ability to participate in local policy decisions.

When the post-Citizen's Discussion survey data were broken out by groups of individuals of different worldviews, those predisposed to lower environmental risk perceptions showed the greatest change in knowledge, impact concern, problem identification, perceived local policy adequacy, and sea-level rise beliefs, and in the direction of increased issue involvement. Although these results are preliminary because of the study's small sample size, they suggest that community-deliberative events may ameliorate the influence of individuals' worldviews about sea-level-rise risks.

15.13 Conditions Under Which Environmental Awareness Represents a Rational Policy Goal

Governmental decisions to raise environmental awareness in a population should be considered based on the typical criteria for good governance: effectiveness, efficiency, legality, and democracy (Bemelmans-Videc 2011). In turn, these can be used to evaluate the types of policy goals for environmental awareness campaigns addressed in this chapter: in advancing behavioral change among individuals, and by default across populations; in facilitating democratic participation processes; and in promoting long-term community-level changes in education, values, and mores for better cooperative environmental decision-making. In conclusion, I review these arguments.

Behavioral Change As we have seen, influencing knowledge and attitudes is mildly effective in shaping behavior, with effect sizes of about 9 % in some meta-analyses. With small to medium effect sizes, and sometimes extraordinarily large costs for campaigns with enough reach and frequency to reach citizens, the use of environmental awareness alone to change behavior is not an efficient use of government resources. As many others have already suggested, under these conditions, to recommend promoting environmental awareness in and of itself for the goal of pro-environmental behavior change is difficult; using it in combination with other types of interventions that will increase overall levels of effectiveness, or to use "nudges" that do not rise to the level of conscious awareness, makes more sense.

In any case, governments that seek to raise environmental awareness for the purpose of behavioral change should also consider whether environmental awareness, and pursuit of population adoption of a specific behavior, can be justified against the constellation of other cognitive demands that people face with a limited attentional budget, especially vulnerable members of society for whom cognitive resources are already highly strained. Determining specific behaviors or actions to target with interventions may seem straightforward, but in practice can prove difficult, particularly when little quantitative data exists on (a) the aggregate environmental impacts of the behavior, in isolation from other human behaviors and activities, (b) the current extent of behavioral practice, and, (c) the probability of an intervention targeted at a particular factor leading to behavior change. These three factors determine whether a given behavioral change program will succeed. In a world of limited program funds, where multiple behaviors in the population frequently contribute to an identified conservation problem, knowing which programs should be targeted to get the biggest bang for their buck is important (Gardner and Stern 1996).

15.14 Education and Civic Participation for Democratic and Cooperative Decision-Making

The evidence for improved societal and environmental decision-making based on education and civic participation is weak, primarily because of a lack of assessment data for these types of programs. Education and programs such as public deliberation are not likely to be highly efficient in terms of time and resources, because these approaches reach relatively small numbers of citizens at any time unless they are institutionalized. Environmental awareness is most strongly aligned with governance criteria in its support of democratic processes, including legal mandates for public participation. The strength of programs that attempt to raise awareness within the context of cooperative decision-making is in the fact that they emphasize social instead of instrumentalist motivations, which are more likely to be effective, especially for environmental concerns.

As noted by Brulle (2010, p. 91): “It is well known that political mobilization campaigns are more effective and legitimate if they engage citizens in a sustained dialog rather than treating them as mass opinion to be manipulated. The importance of public participation in developing decisions that include concern about the natural environment has been stressed by numerous authors.” Nevertheless, public participation can also be a waste of time and attention if citizens are not able to truly influence the decision-making process, or if the process detracts from more critical decisions for individuals or the community.

15.15 Conclusion

The main lesson from this chapter is that raising environmental awareness is a social process, even on the level of individual persuasive communication appeals. As such, it cannot escape being a part of political discourse; indeed that is the most potent argument for its promotion within public policy. Skocpol (2013) argues that when communication becomes divorced from the negotiations of social groups it loses political relevance and power. Environmental awareness must play a role in public education and participatory decision-making processes for governments to maintain themselves as democracies. The platforms by which this is most likely to be achieved, however, are unlikely to be campaigns that are limited to bite-sized messages; instead, they are more likely to be group processes within and between families, schools, neighborhoods, communities, and nations. Governments will always need to curtail some behaviors, including actions that harm the environment and society, and encourage others. When soft policy measures appear optimal, environmental awareness should be on the table, but so should a number of other behavioral factors and interventions, including regulation, taxes, and other monetary incentives, both negative and positive. Indeed, a recent study found that if I were charged 5 cents per bag in Virginia I would be more likely to remember to bring my reusable bags to the grocery store, regardless of my level of awareness of the environmental consequences of plastic bags (Jakovcevic et al. 2014).

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Chapter 16
Experimental Assessment of the Emergence of Awareness and Its Influence on Behavioral Changes: The Everyaware Lesson

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16.1 Overview

The emergence of awareness is deeply connected to the process of learning. In fact, by learning that high sound levels may harm one's health, that noise levels that we estimate as innocuous may be dangerous, that there exist an alternative path we can walk to go to work and minimize our exposure to air pollution, etc., citizens will be able to understand the environment around them and act consequently to go toward a more sustainable world.

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In order to allow the emergence of the awareness the learning process must take place at a social level, involving individuals both alone and collectively. Participatory sensing, also referred to as urban sensing, involves enabling individuals, groups and communities to gather, document, view, share, and in some cases analyse local observations and data about their surrounding environment. Not all participatory sensing relies on mobile technologies. For example, Francis et al. (2008) comment on the use of low cost noise monitors in a citizen science project in which two communities collected noise data: one in relation to noise nuisance being generated by a local scrap yard and the other, in an objection to an airport expansion plan. However, the use of smartphones as sensory devices, either passively or actively, increases the ability to scale such activities. Cuff et al. (2008) highlight a range of applications in which citizens can be engaged in mobile sensing, predicting a growth in the field and in the numbers of ways in which it will be applied.

The power of the crowd has been recognised as an effective way of generating observations, which might otherwise be difficult to obtain, due to spatial and temporal limitations. This is particularly relevant in fields where traditional sensing relies either on a distributed network of expensive stationary monitoring devices across a target area of interest, or where sensors require physical placement for a specific deployment, or in cases where numerical simulations are needed. Cost and data coverage are key factors. The spatial distribution of static monitoring devices and the associated costs of hiring trained specialists to take measurements and process data reduce the amount of real-world measurements that can be taken. That is why, in the EveryAware project, the two main environmental issues faced, i.e. noise and air pollution, have been approached exploiting a crowd-sourcing strategy. The help of volunteers reduces the hiring costs in a significant way, making unnecessary to hire specialist of air pollution monitoring.

Noise pollution is a problem in cities across the world and is one that is likely to affect an increasing number of people with the majority of the global population now living in urban areas, like the World Health Organization reports (World Health Organization 2010). In Europe, this has been recognised and abatement measures have been introduced in many countries. However, noise pollution, in particular, is an environmental problem that relies heavily on 'top down' approaches, both in terms of communicating the issue, through instruments such as strategic noise maps, but also in the methods used to gather data. For example, strategic noise mapping became a requirement of all Member States under the EU's European Noise Directive (ENDS). The maps are used to estimate population exposure to noise in certain areas, to communicate to the public and as a basis for action plans, as stated in Directive 2002/49/EC of the European Parliament (Commission et al. 2002).

Exposure to noise is not merely a case of annoyance. Researchers have provided a growing body of evidence that suggests that long-term exposure to noise constitutes a health risk hazard and can modify social behaviour, cause annoyance (Passchier-Vermeer and Passchier 2000), increase the risk of cardiovascular diseases (Babisch et al. 2005) and adversely affect levels of attentiveness and the ability to read in children (Haines et al. 2001). The World Health Organisation (WHO) estimated that at least one million healthy life years are lost every year from traffic-related noise in the western part of Europe (Fritschi et al. 2011).

Air pollution is another issue which has an important effect on our health, with an increasing number of studies showing higher risk of respiratory and cardiovascular diseases for people exposed to higher pollution levels, e.g. in Lave and Seskin (2013). In this context, keeping air pollution at bay has been a major priority for policy makers in the past decades. Lots of efforts have been done in monitoring and controlling air pollution. Large scale monitoring networks routinely monitor pollutants. They allow to follow up temporal trends in air pollution. Significant efforts have also been made to make information accessible to the broad public. However, several papers indicate that official monitoring networks do not have sufficient spatial coverage to provide detailed information on personal exposure of people, as for some pollutants, this may vary substantially among micro-environments, like reported in Dons et al. (2012) and Kaur et al. (2007), i.e. in urban, traffic-prone areas where spatial variability is very high (Peters et al. 2013; Setton et al. 2011). Several pollution sources have been addressed with success. However, persistent problems remain in urban areas, where traffic and domestic heating are important sources, like stated in the European Environment Agency report (European Environment Agency 2013). Next to the technical solutions (e.g. electrical mobility), people's personal perceptions, behaviour and choices play a major role in addressing these issues and to facilitate change in a bottom-up manner.

In the EveryAware project we addressed to these two main environmental challenge with an aim far more complex then just measuring pollution exploiting the power of the crowd. The goal of our work was the improvement of the involved crowd awareness about those environmental issues and the analysis and the modeling of the dynamics of this improvement. In this chapter we present results from participatory sensing performed using the WideNoise and AirProbe applications and the EveryAware sensor box. We exploit objective and subjective data to provide an analysis of user behaviour/opinions and environmental awareness. In particular, we report on data collected during two large scale test cases: the Heathrow noise pollution test case, organised in London (UK) and the AirProbe International Challenge (APIC) (AirProbe International Challenge 2013), organised simultaneously in four cities: Antwerp (Belgium), Kassel (Germany), London (UK) and Turin (Italy).

16.2 The Noise Test Case

The implementation of the noise test case has already been described in chapter by Theunis et al., in chapter by Atzmueller et al. and in chapter by Nold et al. in this volume. By means of the subjective data collected during measurements an analysis of users awareness will be presented in the following. Subjective data, gathered thanks to the WideNoise app, consists essentially of guesses of the noise level, tag annotation and perception annotation (love-hate, calm-hectic, alone-social, natural-man made) performed contextually with the measure. Widenoise application allows its users to guess the noise level before the actual measurement with the help of a slider ranging from 0 to 120 dB. Also, the choice of the noise level measured can be considered a subjective data. The interest is in assessing whether usage of the application leads to any change in behaviour, and whether this change indicates an increase in awareness of environmental noise and its effects. For this study, only data collected by users not belonging to the EveryAware consortium is considered (38267 measurements).

A first analysis of awareness/learning involves studying the decibel values estimated by users, in comparison with the measured values. Figure 16.1 displays the estimated vs real noise level, with light-coloured small points corresponding to early measurements by a single user, while dark large points corresponding to later measurements. Hence, the size and darkness of points displays user expertise. The figure shows larger darker points closer to the diagonal compared to lighter ones, which means that the estimation is closer to the measured value for later measurements. This indicates that during repeated usage of the application the ability of users to guess the noise level around them increases, hence the user learns in time.

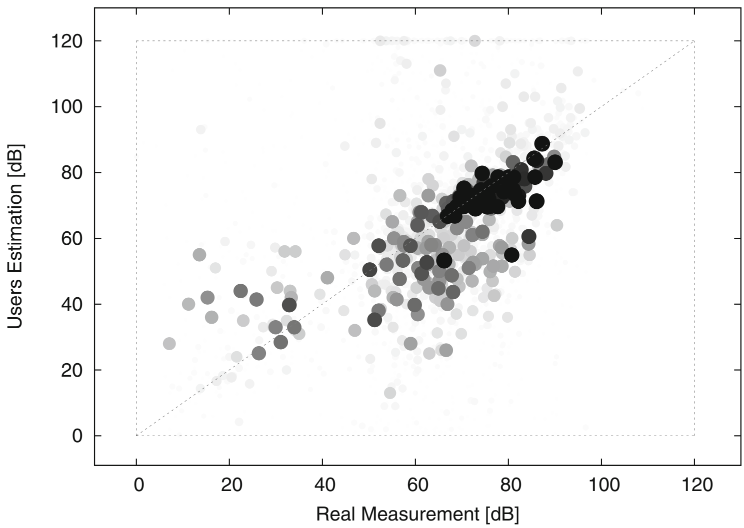

Fig. 16.1 Estimated versus measured noise. Each *point* corresponds to one measurement, while both the colour scale *light to dark grey* and the *point size* represent the user expertise (the first measurement of a given user is depicted with the *smallest and lightest point*, and are almost invisible; points get *darker and larger* as users go on with their measures). The graph shows how, with the experience, users become more precise. In fact, *larger and darker points*, which represent more experienced users guesses, are closer and closer to the measured value

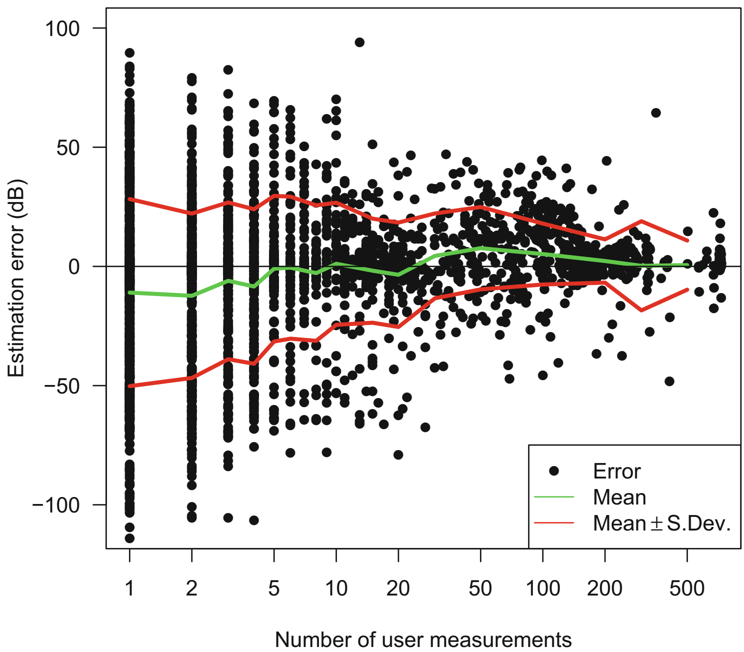

Fig. 16.2 Estimation error. Difference between estimated and real dB value vs the number of measurements a user has performed

To emphasise this point, Fig. 16.2 shows the difference between the estimated and the real noise level as the users repeatedly perform measurements. Averages and standard deviations are also displayed. This shows that as the expertise increases (number of measurements by the same user—horizontal axis), the errors become closer to zero and deviations from the mean decrease.

Considering this, it would be also interesting to see what range of noise is typically measured, and whether this changes in time. Figure 16.3 displays the distribution of noise levels recorded by all users during their first five measurements, compared to those submitted after having already made 50 measurements (43 users have submitted at least 50 measurements). This shows that the noise levels of experienced users are higher than those of novices, indicating that as users become more involved in measurements they tend to concentrate more on areas with high noise levels, or viceversa users living in noisy areas become more involved in measurements. This could be on one side due to the users learning how to estimate the higher levels of noise, but also due to an increased interest in documenting higher levels of noise in their area.

A different indicator of user involvement and hence awareness is the amount of tags submitted by users. An increase in repeated application usage would indicate increased involvement in data collection and hence increased awareness. Figure 16.4 displays the average number of tags per measurement, considering all measurements

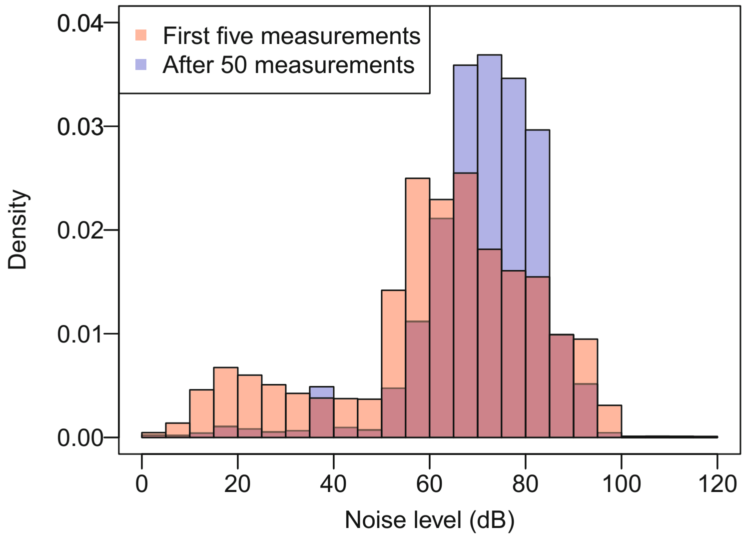

Fig. 16.3 Distribution of measured noise levels. The plot shows the histogram of noise levels for the first measurements performed by users, compared to those performed after some experience is gained (after the 50th measurement)

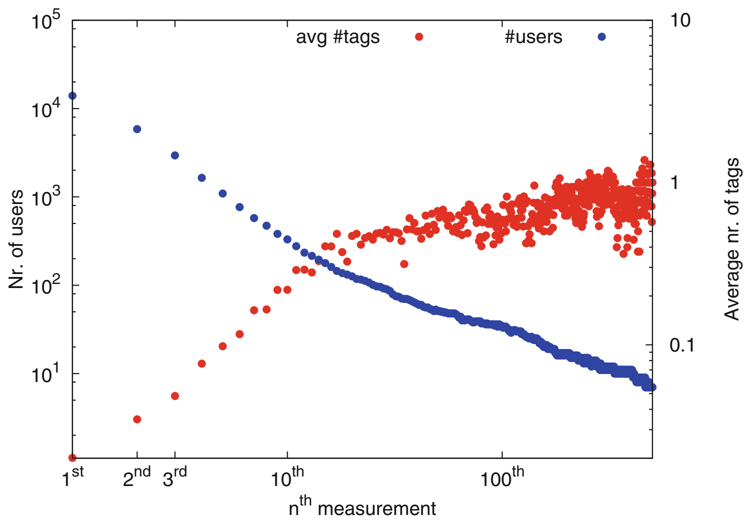

Fig. 16.4 Tagged measurements for different expertise levels. The total number of users submitting at least *n* measurements is displayed in *blue* (*left axis* legend), while the *red points* represent the average number of tags used in the *n*th users' measurement (*right axis* legend). Both axis are logarithmic

submitted to the platform, for increasing level of expertise (measurement number). At the same time, the number of users who have passed a certain expertise level is displayed. This shows that as the users perform more measurements, although the number of users here decreases, the average number of tags per measurement tends to increase. This demonstrates an increase in user involvement and dedication to the task, hence in the level of awareness.

A further analysis aims to compare the subjective perceptions (Love-Hate, Calm-Hectic, Nature-Man Made, Alone-Social) of the users with the measured noise levels. Out of all measurements performed, 12129 contain intentional perception data. We considered perception data as intended if at least one of the sliders was moved from the default position (0.5). Figure 16.5 shows how these perceptions depend on the measured noise levels. As expected, the perception values increase

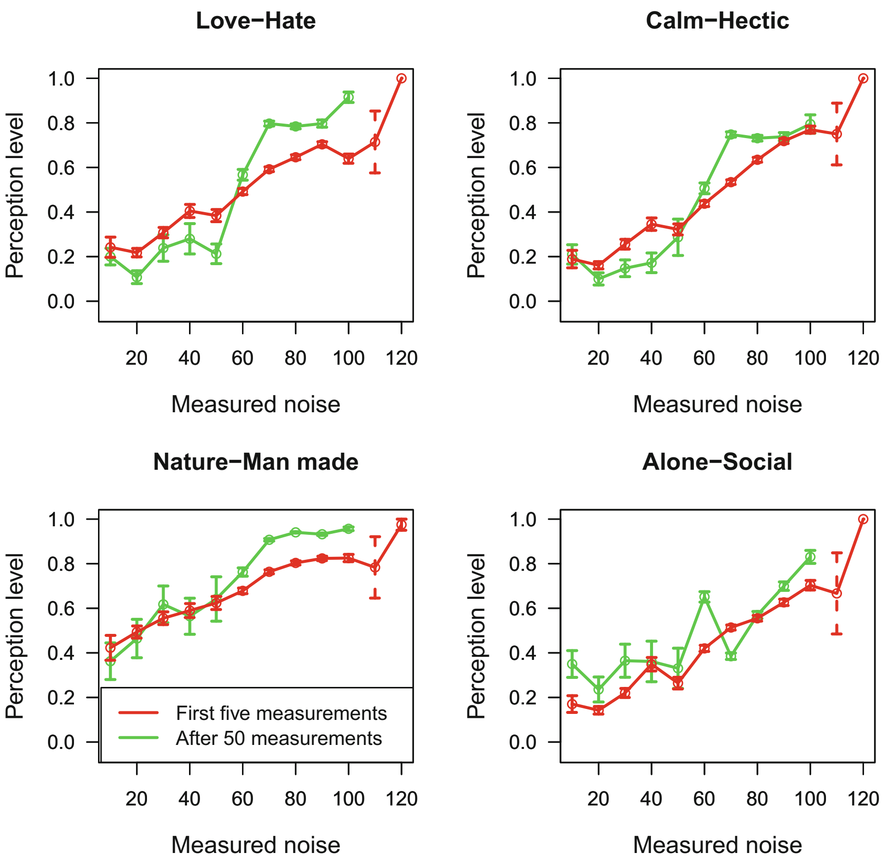

Fig. 16.5 Perception evaluation versus the measured noise level. The *red lines* display the average evaluation over the first five measurements of all users; the *green lines* correspond to the average evaluation over the set of all measures taken by users starting from the 50th one

with noise. This means that, in general, users ‘Love’ quiet places, finding them a ‘Calm’ environment, while they ‘Hate’ loud ones finding them ‘Hectic’. At the same time, high levels of noise are in general associated with Man-Made and Social environments.

To analyse the change in opinion as the user is exposed to the information from the application, i.e. the real noise level, Fig. 16.5 includes two curves. One shows average perception levels for the first five measurements of every user, as a function of noise, while the other shows perceptions for measurements performed after some expertise has been gathered, i.e. more than 50 measurements. The two curves seem to show a different behaviour for novice and expert users, for all perception types except for the Alone-Social evaluation. Specifically, noisy environments appear to be perceived as less pleasant and more artificial as the users become more experienced, while quiet environments as more natural and lovable. A sharper switch between the two possibilities is observed around 55–60 dB, for all three types of perceptions, indicating this as a threshold where noise becomes bothersome. This might mean that indeed, exposure to information from the noise application does influence the way in which users perceive the environment. Experienced users have a more stringent evaluation of their environment, and stronger opinions about how much they love or hate the noise levels around. A categorisation of the noise levels appears to emerge, with plateaus visible for high and low levels of noise, when considering data from experienced users. Although it cannot be excluded that experienced users might push the sliders to the extreme right or left edges so to minimize the cognitive effort inherent in judging the quality of noise, the voluntary act of modifying the slider position, by setting it away from the neutral central position, indicates the willingness in conveying a useful information. In that case, we would interpret the pushing of the sliders to the extremes as a conscious act of categorization of experienced users who got more confident with the App. As for the nature-man made indicator, we note that the typical user of our App lives in an urban environment (all the main cast study happened in urban environment), so that there are fewer samples collected in a natural environment and the error bars associated with the measures are consequently larger, possibly hiding the categorization effect seen in the other indicators at low dB values. The social aspect, however, does not change with repeated usage of the application, since knowing the noise levels does not affect the user’s perception of how many individuals there are around. This explains why there is no definite difference between the two curves in Fig. 16.5, lower right pane.

16.3 The Air Quality Test Case

During this test case, volunteer participants were asked to get involved in two activity types. One consisted in using a sensing device (Sensor Box, which has been introduced in chapter by Theunis et al. in this volume), to measure air pollution (black carbon (BC) concentrations) in their daily life, generating what we call objective data. The second activity was playing a web game (AirProbe), where volunteers were asked to estimate the pollution level in their cities, by placing flags (so called AirPins) on a map and tagging them with estimated black carbon (BC) concentrations on a scale from 0 to $10\,\mu g/m^3$, resulting in subjective data on air pollution (perception). Volunteers involved in the measuring activities were also encouraged to play the game and bring other players as well.

The two data types allow for an analysis of user behaviour and perception throughout the challenge. To enable this, the test case was composed of three phases. In phase I, only the online game was available, so we could obtain an initial map of the perceived air pollution. In phase II the measurements started in a predefined area in each of the cities (corresponding also to the game area), with the web game running in parallel. Phase III introduced a change in the game, so that players could purchase information about the real pollution in their cities. At the same time, measurements were continued, this time without a restriction of the area to be mapped.

Volunteer involvement and activity levels are among the most important elements in participatory monitoring campaigns, since these can decide the faith of entire project. Minimal activity is required for acquiring data, both objective, for analysis of the environment itself, and subjective, for analysis of social behaviour. The test case presented here has successfully involved 39 teams of volunteers in four european locations, gathering 6,615,409 valid geolocalised data points during the challenge (the measuring device collects one data point per second). An additional 3,326,956 data points were uploaded to our servers in the same period, but missing complete GPS information, so were not included in the analysis. Some of these measurements contained labels (tags), with 742 geo-localised tags coming mostly from one location of the challenge (London).

Additional information on perception of pollution has been extracted from the online game. The platform had 325 users in total, over 6 weeks, 97 of which played the game at least ten times. Their activity resulted in 70,758 evaluations of pollution (AirPins) at the end of the test case. However, some other AirPins had been added or values had been modified during the challenge, so that the entire data used was much larger.

For insight into measurement coverage patterns and how these evolved during the test case, Fig. 16.6 displays coverage in space obtained every week, together with the overlaps between the different weeks. Space coverage is computed by dividing the area of each of the four participating cities into 10 by 10 m squares (tiles). One square was considered covered if at least one measurement was performed within its area. Overlaps are obtained through the intersection of covered tiles in different weeks. Both overall values (use entire dataset to mark tiles that are covered or not), and team averages (compute coverage and overlap for each team then average over all) are displayed. The former provide insight into the quality of the dataset obtained, while the latter indicate measuring strategies.

Overall coverage shows that every week all volunteers mapped more than $5\,km^2$, with higher values in the first 2 weeks. This is probably due to the fact that in these two weeks they were instructed to cover as much as possible from a specific area,

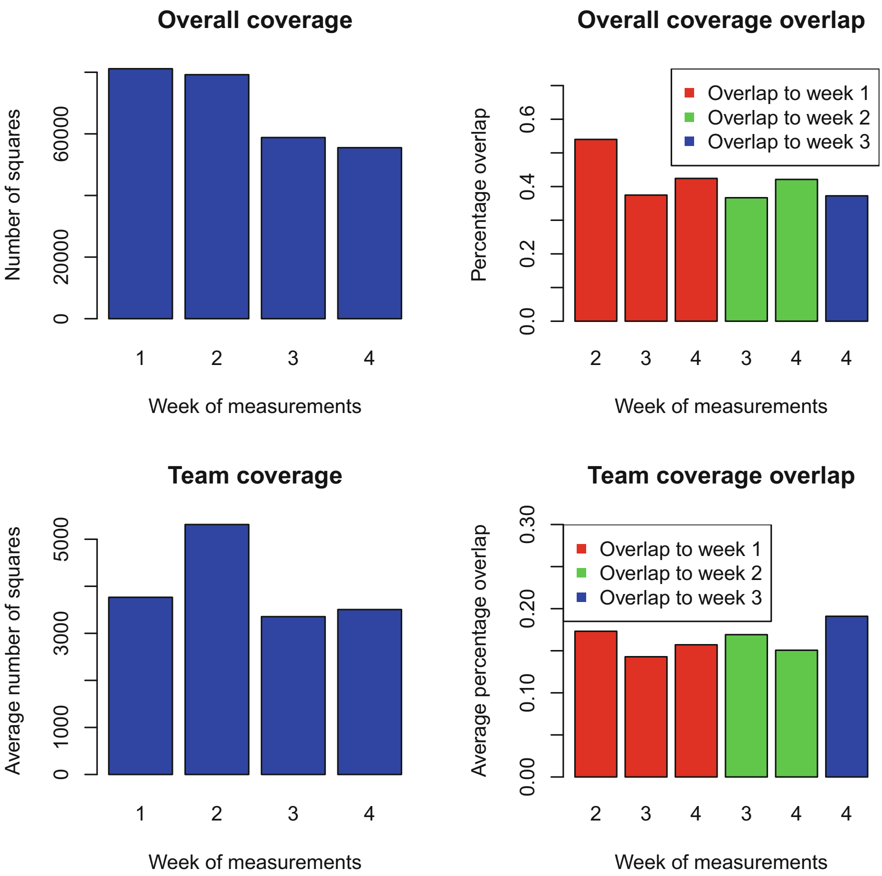

Fig. 16.6 Coverage per week and overlap between weeks

while in the second fortnight they were asked to use the sensor box how they wished. Pairwise comparison of the different weeks shows over 30 % of the area is covered in at least two weeks. The overlap between the first two weeks reaches over 50 %, while following weeks have less overlap. This indicates that one can obtain good coverage both in time and space by indicating a restricted area for mapping. Also, this appears to indicate that during the last two weeks of the challenge volunteers explored more, since the overlap between weeks is lower.

To test this hypothesis, we also include averages per team for coverage and overlap in Fig. 16.6. Coverage is very high during the second week of the test case and comparable for the rest. This may be because the main prize of the challenge was given for second phase activity, i.e. at the end of the first fortnight of measurements. So, volunteers made an extraordinary effort the week before the prize, after a first week of exploration. Overlap on the other hand gives opposite indications compared to overall values. The highest overlap, of about 20 %, is seen during the last two weeks of measurements. This means that volunteers make more measurements on the same path than in the first 2 weeks, so they explore less. This indicates that while in the first weeks they explore wider areas because of the incentives, when these are removed they reduce the area of interest, probably to most familiar and frequented locations. The overall values (top-right panel of Fig. 16.6) seemed to indicate more space exploration during the last phase, but this was an artefact of the fact that the area was restricted in the first two weeks, so overlap between volunteers was much higher, increasing the overall overlap as well.

The measured BC levels can also provide useful insight into the aims and strategies of the volunteers during the challenge. The two measuring phases (phase 2 and 3 of the test case) gave different tasks for the volunteers. In phase 2, they had to concentrate on covering as much as possible a specific area, while in phase 3 they could explore any area they wanted. It would be interesting to understand if the measured BC levels changed between the two phases. Of course, pollution levels themselves may change from one day or period to another. In order to measure the change in BC levels due to change in behaviour and not due to actual changes in the pollution levels, we need reference pollution data for the days of the challenge. For all four locations, average daily PM10 (particulate matter smaller than 10 μm) values were obtained from public repositories and used as a baseline for normalisation. BC levels were not available for the same locations, however PM10 correlates very well with BC levels, so can be used also as a baseline (in general, PM10 concentrations are more or less 10 times larger than BC levels, e.g. like reported in Vanderstraeten et al. (2011)). These daily averages were used to scale all measures performed by our volunteers. In the following only these normalised BC levels will be used to build the discussion on real measurements.

Figure 16.7 shows histograms of normalised BC levels measured in the two phases, and we can observe larger BC values in phase 3. One could argue, in this situation, that probably most of the measurements in phase 2 were within the monitoring area, which we selected in the city centre, where limited traffic zones exist, so that could explain the difference in BC levels between the two phases. This is why we show data from within and outside the monitoring areas separately. The increase in BC levels in visible for both cases, so we believe it is due to the interests of the volunteers, and does not depend on the area to be monitored. When they can choose freely where to make measurements, volunteers appear to be driven to trafficked more polluted areas, since it is those locations what they want to identify first.

To look into this even further, Fig. 16.8 shows the distribution of normalised BC for the different locations, compared in the different phases. Again, data inside and outside the monitoring areas is shown separately, and the box width highlights the significance of the normalized value based on the size of the averaged set. In Kassel, volunteers were grouped into two groups in phase 3: the first group (g1—three users) had as a task to avoid highly polluted areas, while group g2 had no task other than using the sensor box where they wished. This, in order to test whether any learning appears during measurements.

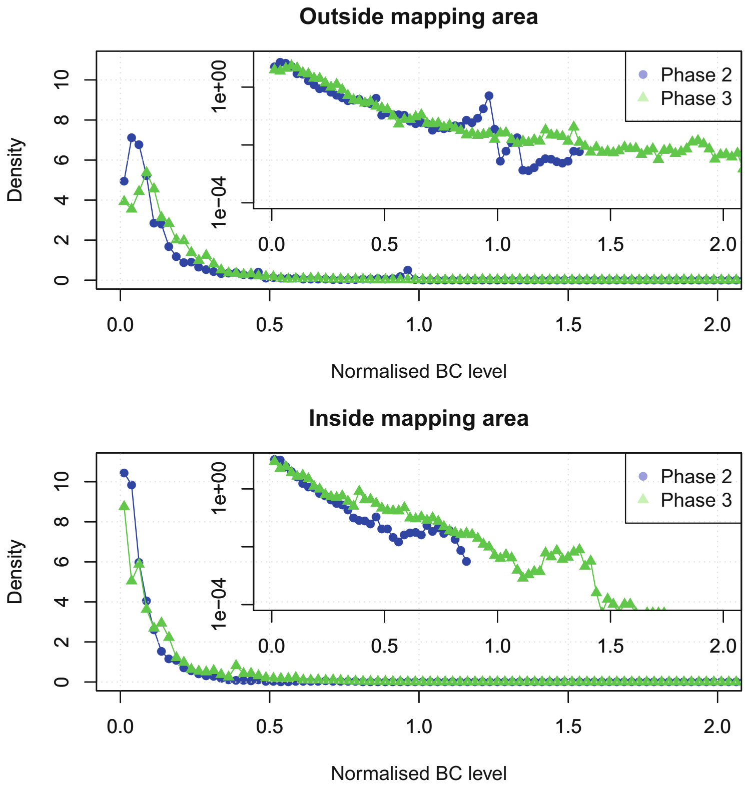

Fig. 16.7 Overall pollution levels compared between the two phases. BC levels normalised by scaling with average daily PM10 concentrations are shown for the two measuring phases of the challenge. The data measured within the monitoring area of phase 2 is considered separately from that measured outside, to control for the different setting. Inset graphs logarithmic version of the plots

For Antwerp, volunteers collected higher BC levels in phase 3, both outside and inside the monitoring area. In London, although means are not larger, the maximum levels achieved are larger in phase 3. However, for these two cities data in phase 3 is rather limited compared to the other locations and to phase 2 (as shown by the width of the boxplots in Fig. 16.8). For Turin, an increase in the measured pollution levels is clear outside the monitoring area, but not visible inside. So, for all three locations, there is a good indication that volunteers concentrated more on high pollution levels in the 3rd phase of the challenge: when they were allowed to explore, the aim was to identify highly polluted locations.

For Kassel, the group supposed to minimise their exposure displays lower BC levels compared to the other group only inside the monitoring area, while outside this they measure higher pollution levels. Maximum values appear, however, to be lower than the previous phase. This indicates that volunteers have successfully

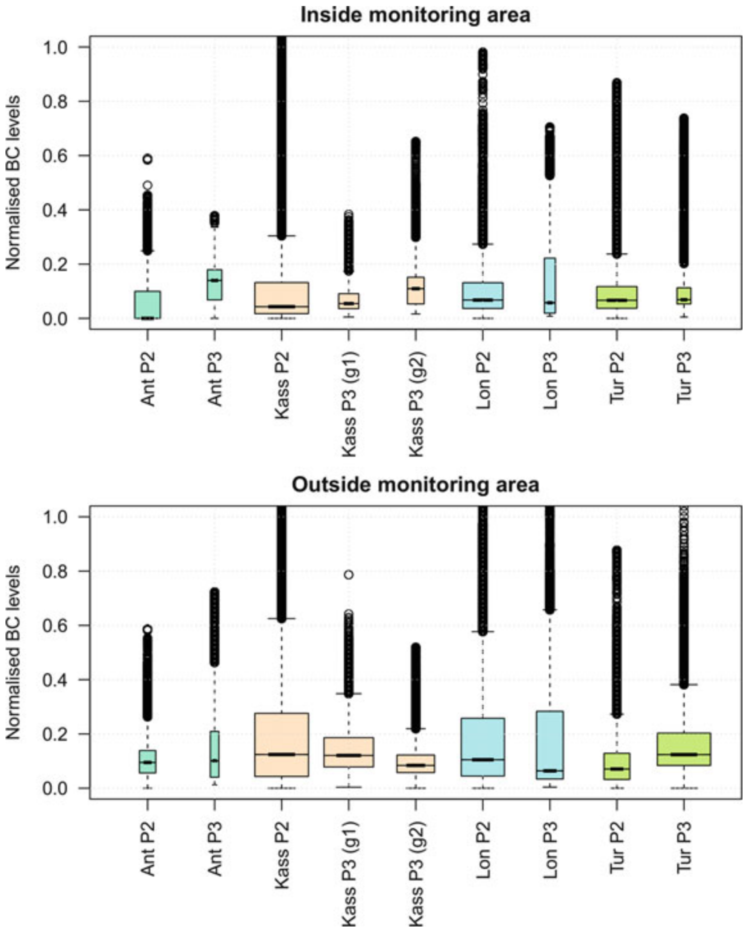

Fig. 16.8 Pollution levels per location compared in the two phases. The distribution of BC levels, normalised by scaling with average daily PM10 concentrations, are shown for the two measuring phases of the challenge, separate for each location. The data measured within the monitoring area of phase 2 is considered separately from that measured outside, to control for the different setting. Width is an indication of the size of the dataset

learned how to avoid high pollution levels within the monitoring area, after two weeks of exploration. However, they are not fully able to extrapolate this knowledge to unseen locations, although they do manage to avoid very high pollution spots.

One question is why the exploratory behaviour, keen on higher pollution levels, seen in phase 3, when volunteers are free to use the sensor box where they want, does not also appear in phase 2. A possibility is that the exploration does happen at the beginning of the phase. However, given that the area is restricted, this stops after some time and afterwards the only aim remaining is covering the area. To check this, we have looked at average normalised BC every hour of measurements, for each

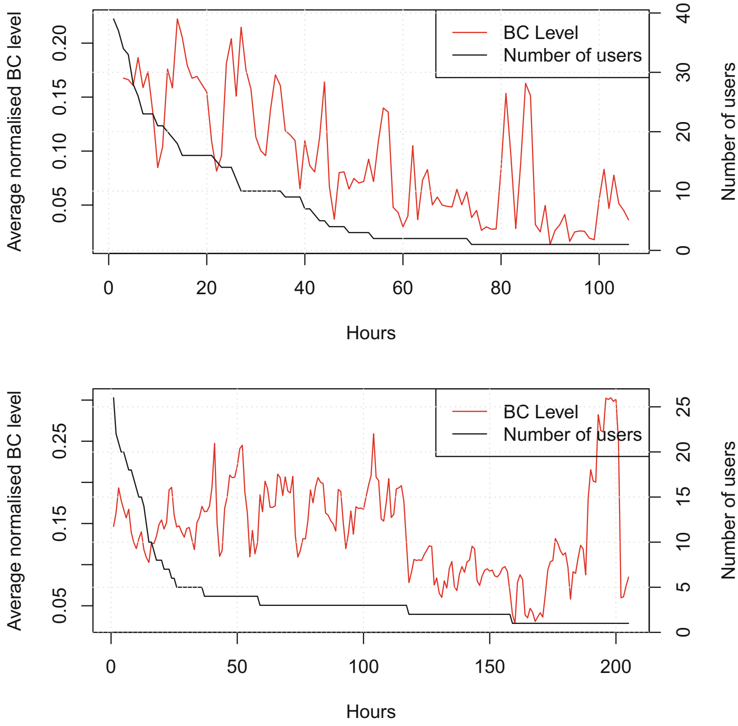

Fig. 16.9 Pollution levels and user experience. Average normalised BC levels are shown for all users, by considering 1 h of measurements at a time. Hence, the horizontal axis can be viewed as user experience, i.e. how many measurements they have performed, with the *red line* showing how the hourly BC level changes as the user makes more measurements. The *black line* shows the number of users that reached a certain experience level (for instance, in the top panel, only two users performed 60 h of measurements, so only their data is displayed). The *top panel* corresponds to phase 2, while the *bottom panel* to phase 3

user, and then averaged this over all users. Figure 16.9 shows the values obtained in the two phases. It is important to note that here the time axis represents user experience: the first point represents an average over the first hour of measurements for all users, the second the average over the second hour of measurements, even these may have happened at totally different times for each user. For instance, if a user decided to start their activity on the second day of the test case, then their first hour will be one day later than the other volunteers. For this reason, as the number of hours increases, the number of users that have reached that level of experience decreases, and this is also shown in the figure.

Indeed, measurements made in the first hours of sensor box usage, in phase 2, yield larger BC levels, indicating that at first volunteers looked for highly polluted spots. As they become more experienced with the box, and they identify more such locations, the BC values they measure decrease slowly (although fluctuations remain), indicating a loss of the exploring interests. This could also indicate volunteers are learning how to avoid highly polluted spots. The same patters is preserved if volunteers with a low total number of measurements are excluded from the beginning from this analysis. Another possible interpretation implies the presence of some users who are concerned about air pollution problem. So they tend to avoid pollution and, since they are really engaged (because of their concerns) they measure air quality longer. So at the end the air pollution line goes lower.

For the third phase, however, no decrease is visible in the measured BC levels, until the number of users becomes very low (2), where fluctuations may be due to local variability so are not relevant. Hence, indications are that during this phase users continued their exploration for the entire two weeks, since there was no limitation on the area to be covered.

The analysis of the structure and location of the collected objective data gives some insight into what volunteers are interested to see when measuring air pollution and whether any learning appears. Subjective data, on the other hand, can provide a stronger indication of changes in perception. For this, we look at data collected through the web game, which consists of perceived levels of pollution geolocalized in the mapping area. These were obtained by asking players to place on the map AirPins, geolocalized guesses of the air pollution levels. Figure 16.10 shows the distribution of the perceived pollution at the end of each phase of the challenge.

Data from the first phase represent the original perception of air pollution by the volunteers: during this phase, players had no access to sensing devices nor any data.

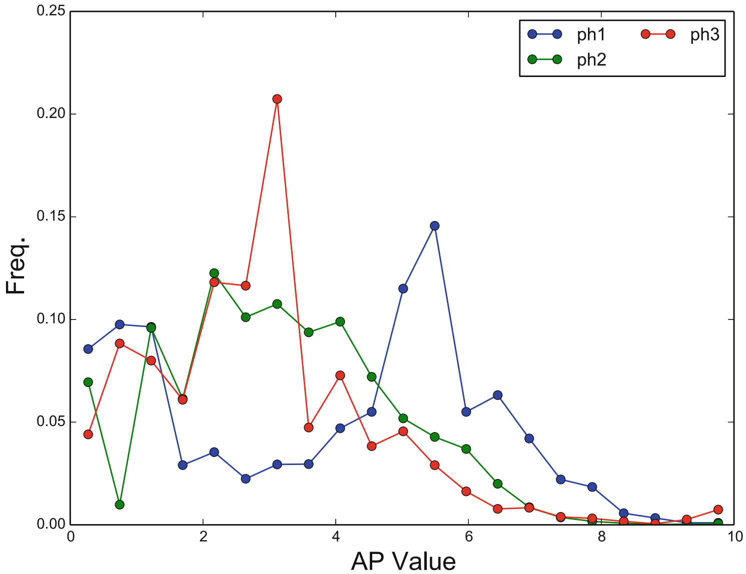

Fig. 16.10 Web game subjective data. The plot shows the distribution of perceived pollution levels (AirPin values) collected at the end of each phase of the test case

The distribution of pollution levels appears to be bimodal, which is an indication of a categorization effect. Volunteers divide the locations into those with very low pollution and those with higher pollution. The higher pollution levels peak around the middle of the pollution range, with larger and smaller values also present. This indicates that players took the middle of the range as a medium pollution level and moved around this to tag the different locations in the city.

In the second phase, however, some volunteers were given the sensor boxes to start performing measurements. The web game players consisted of these volunteers plus a set of other players recruited by them, so from their friend circle. No data, except for the direct feedback from the boxes, was shown to the volunteers. Even so, a change is visible in the distribution of perceived pollution levels reported in the web game. Volunteers see that in general BC concentrations are lower than what they believed, and respond by changing the values of the AirPins. Since the change is quite significant, we also believe that those volunteers with the sensor boxes spread the information about what they were measuring, so that all players changed their perception. This decrease in the pollution levels reported in the subjective data of phase two is a very strong indication of learning during this phase.

In phase three, perceived pollution levels decrease even further. However, here the mechanism is different. Players are now allowed to purchase information about average pollution in different map tiles (called AirSquare), so they can now adjust their guessed pollution levels based on that. So, in this case the change is triggered from within the game, while in phase two the change appeared naturally from the user experience outside the game.

16.4 Emergence of Awareness in the AirProbe Web-Game

By playing the AirProbe web-game users are exposed, in phase III, to the air quality measures collected by the Air Ambassadors (volunteers equipped with sensor boxes). Therefore they are somehow learning the air quality status of their environment. However, it is not well justified to assume that what is learned by players within the game is equivalent to awareness. Awareness is a slow process with long characteristic time scales so that it is not feasible to measure it in a short lived experiment as this one. Nevertheless, we can try to understand whether, in the game context, the behaviour of players differs from the trivial task of setting AirPins (AP) values just by copying the value shown by the purchased AirSquares (AS). If any systematic difference is detectable we could ascribe it to a sort of an opinion shift toward a virtual awareness. To this aim we shall report here the evolution of the difference between the AP value and the value of the AS it belongs to. This difference will be referred to as AP difference (APD) in the following and is displayed as heat maps in Figs. 16.11, 16.12, and 16.13 for the city of Kassel, London and Turin, respectively. Antwerp dataset was discarded because of its negligible size.

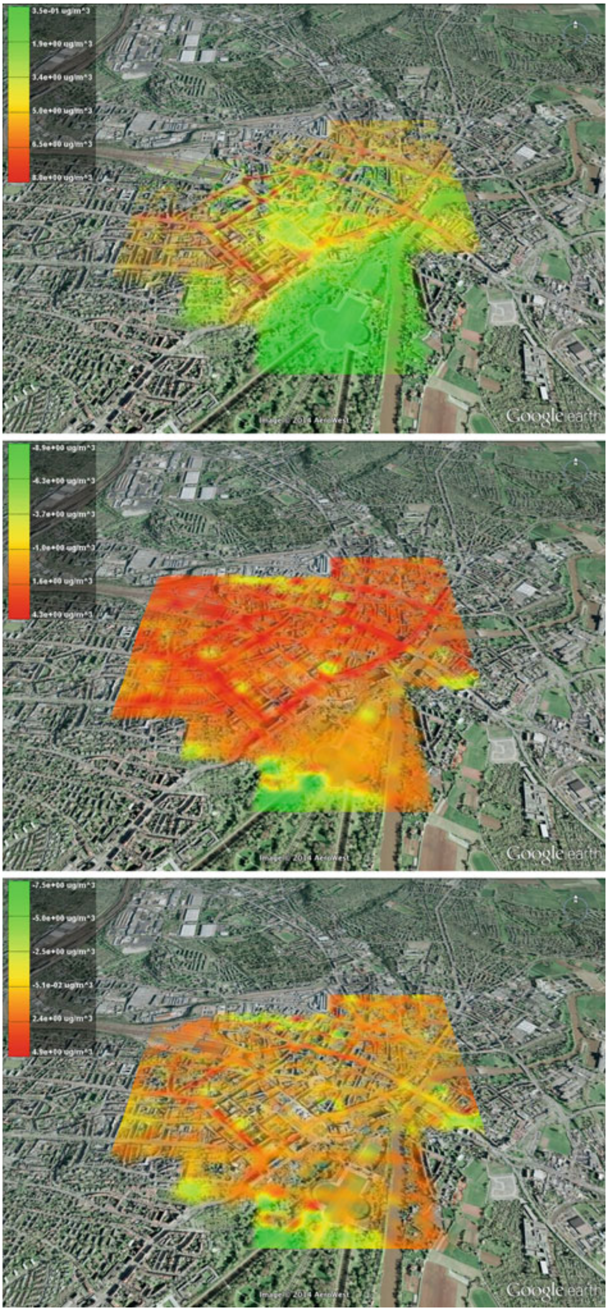

Fig. 16.11 Heat map of the APD values (difference between the web-game annotated AirPin value and the AirSquare value inferred from on field sensor box measurements) for the city of Kassel. *Top figure* refer to phase I, the *middle one* to phase II, the figure at *bottom* to phase III. Values in the legends represent $\mu g/m^3$ concentration of Black Carbon. The opacity is related to the number of AirPins used in the corresponding point

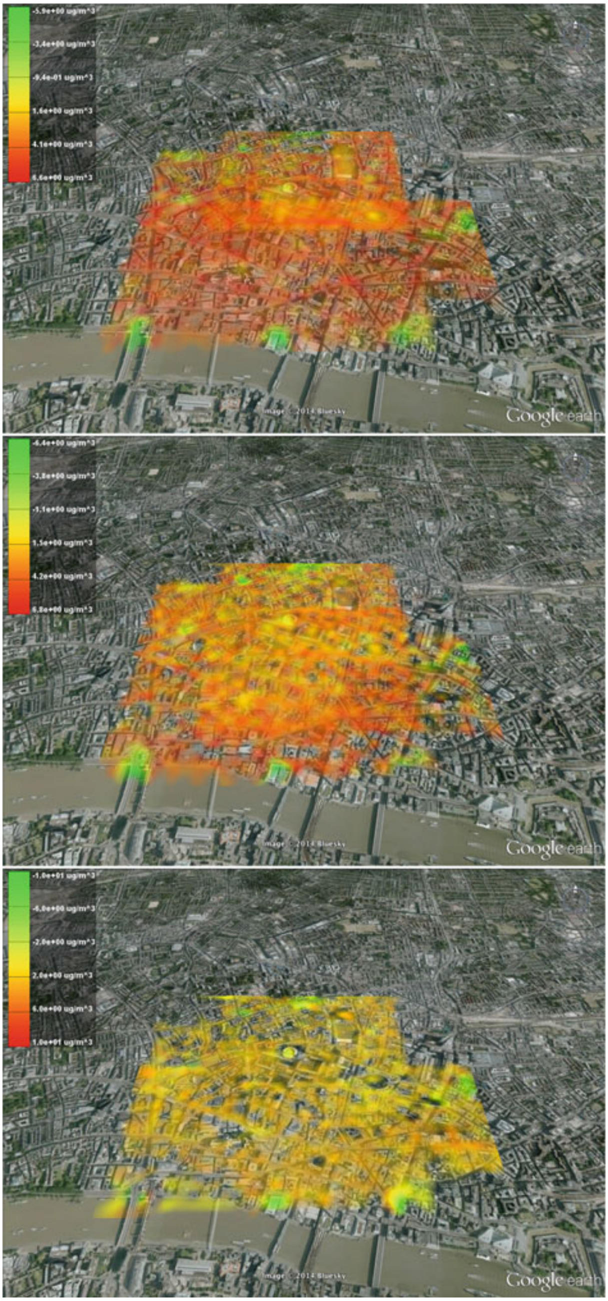

Fig. 16.12 Heat map of the APD values (difference between the web-game annotated AirPin value and the AirSquare value inferred from on field sensor box measurements) for the city of London. *Top figure* refer to phase I, the *middle one* to phase II, the figure at *bottom* to phase III. Values in the legends represent $\mu g/m^3$ concentration of Black Carbon. The opacity is related to the number of AirPins used in the corresponding point

Fig. 16.13 Heat map of the APD values (difference between the web-game annotated AirPin value and the AirSquare value inferred from on field sensor box measurements) for the city of Turin. *Top figure* refer to phase I, the *middle one* to phase II, the figure at *bottom* to phase III. Values in the legends represent $\mu g/m^3$ concentration of Black Carbon. The opacity is related to the number of AirPins used in the corresponding point

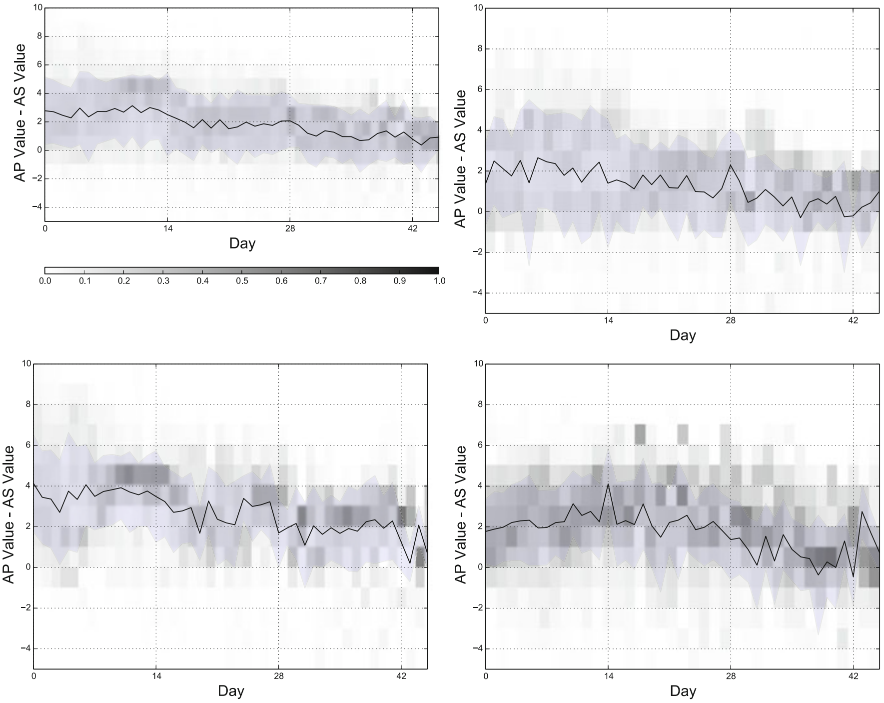

Fig. 16.14 Distribution of the APD values in time. *Each column* displays the histogram of APD in the given day with each bin painted in a *gray scale level* related to the relative importance of the bin (white means no APDs fall in the bin, *black* means all APDs fall in the bin). Bin size is $0.5\ \mu g/m^3$. The *curve* shows the average daily value while the *blue area* the corresponding standard deviation. The plot at the *top left* is calculated for the overall set of data, while, going on clockwise, the other plots refer to Kassel, Turin and London respectively

Once more, we observe the effect of the overrating due to the wrong scale usage in the first two phases. Interestingly, the maps related to phase III indicate that players tend to overestimate the values in those places that were previously annotated as very polluted. We will analyze this kind of effect in detail in the following.

In order to understand what is going on here time is a key factor. Thus we measured the evolution of the opinion with the histogram of APD daily values reported in Fig. 16.14, where we also added a line showing the daily average and a bluish region depicting the corresponding standard deviation. Overall, players are overestimating the pollution of their environment, though it is not clear whether this is a result of being rather pessimistic or of not having correctly grasped the scale used to report the air quality parameter chosen. After each change of phase, i.e. at day 14 and 28, a major shift of APD can be spotted (except in the case of London at day 14). In each shift, the APD decreases, showing that people begin to understand better the black carbon scale used in the game and are improving their evaluations. At day 14, i.e. at the switch between phase I and II, Air Ambassadors started their measuring activity and sharing information with Air Guardians (players of the web-game) of their teams. Moreover, at day 14 some rules of the game changed by stimulating players to be more precise in their estimations. This kind of transition seems to be quite fast, since the shift takes only few days both in Kassel and in Turin (in London there is a slightly different situation). The substantial steadiness of the APDs along the duration of each phase allow us to consider phase-aggregated data in order to answer to the original questions: how does the shift take place? Are volunteers learning something from the game or are they just blindly copying the AS values?

Let us now look at the APD histograms aggregated according to each phase. Since the time scale for opinion shift seems to be very short and the opinion distribution seemed to be more or less constant, data aggregation by phase sounds reasonable. We are interested in how the exposure to information affects opinions, so we will consider only those APDs for those AirPins whose relative AirSquare was effectively purchased by the user. The assumption about the opinion stability during each phase is particularly important in phase III. This implies that in the last phase players bought a great number of AirSquares in the first days and in those days their opinions changed. So we can consider all AirPins of phase III as projections of the opinion shifted as a consequence of the exposure to the AirSquare information. How this reflects on the APD distribution is reported in Fig. 16.15.

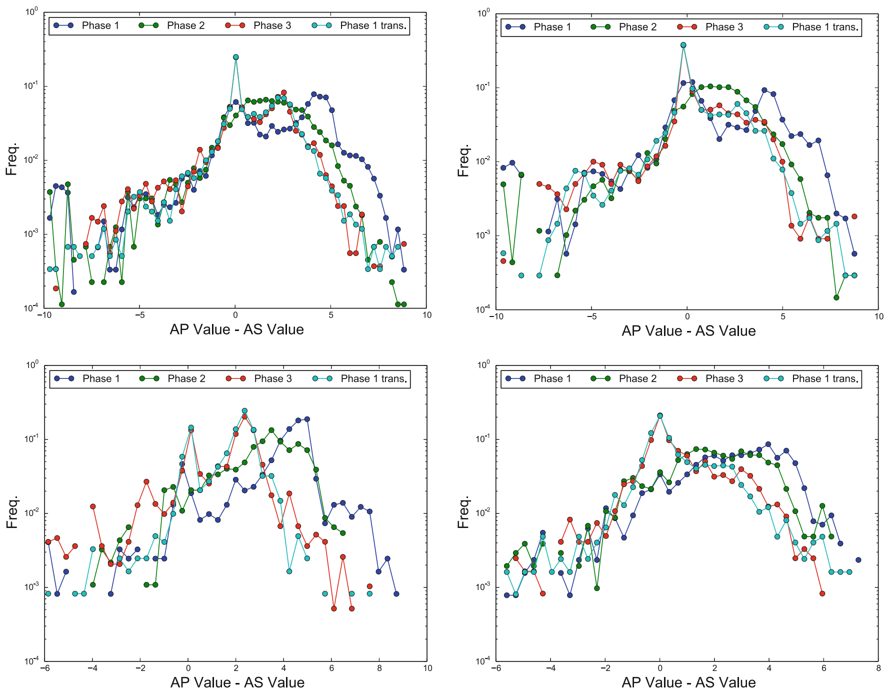

Fig. 16.15 Clockwise, from the *top left*: the APD histogram for the overall, for Kassel, for Turin and for London in each phase of the challenge and with an estimation of phase III data obtained from phase I data through the transformation defined in Eq. (16.2)

If we look at phase three histograms two main features attract our attention: a narrow peak in 0 and a deeply asymmetric structure. The first feature was somehow expected since players are trusting the AS values shown in the AS, and they are annotating accordingly. Fortunately, the peak at zero is not delta like, what is expected for users copying the AS value. Rather players still have their opinion on the environment and keep it despite the on field measurements. This may happen because they are really trying to follow the basic ideas of the game but also because copying it is not the best strategy, since they know that the AS value is aggregated, i.e. it is the average of all sensor-box measures taken in the corresponding AS, while the real measurements used for revenue calculation were punctual values which could be substantially different. So the shape of the distribution around zero seems to be caused by users learning the most likely air quality value and trying to estimate fluctuations. But graphs in Fig. 16.15 show something more. There is a clear asymmetry for phase III distributions, since the great part of APD values fall in the positive range. This could be a consequence of the fact that AS values were around 3 $\mu g/m^3$ so there was a 30 % probability to underestimate that value and 70 % to over estimate, but if we look at the phase I distributions, this asymmetry effect seems better explained by a sort of memory effect or inertia of players in changing their opinions. This hypothesis seems realistic if we look at the London graph. The main peak around 4 $\mu g/m^3$ is still present in phase III, although it is shifted. In order to measure this effects we defined a transformation that takes into the account both features just discussed: the accumulation around 0 and the shift. Let us consider a given set of opinions o_i about a certain number of topics provided by a certain number of subjects. At a given time those subjects are exposed to values h_i, which are perceived as hints of the true values. We are interested in what happens to the difference between opinions and hints before and after the exposition, to understand how this information will affect the opinion structure. To this aim, we define the set of differences d_i between the opinions and the relative hints and analyse the distribution of those difference before and after the exposition. Obviously, the variation of the differences is only due to the variation of the opinions. As we said, we want to reproduce the phenomenon of the accumulation around the hints (i.e., $d_{aft} \sim 0$) and the shift of the general opinion, that we will try to describe as a sort of rescaling (i.e., $d_{aft} \sim d_{bef}/r$ where r will be the rescaling constant). Which of the two phenomena will take place will be decided randomly: with a given probability p_0 the opinion will reset around 0, otherwise, with probability $1 - p_0$, the opinion will just be rescaled. Finally, around this two attractors we add a certain amount of noise. We decided for a Cauchy distribution $C(X)$ centered in 0 in one case and in d_{bef}/r in the other, i.e.

$$C(x; \mu, \gamma) = \frac{1}{\pi\gamma\left(1 + \left(\frac{x-\mu}{\gamma}\right)^2\right)} \tag{16.1}$$

where μ is the average (and the center of this symmetric distribution) and γ represents a scale factor. It is worth to note that the variance of this distribution is not defined, since the second momentum of the distribution does not converge. This choice seems reasonable because tails seem to be power law-like rather then gaussian-like, as the log plots in Fig. 16.15 show. Let us define our transformation and its effect on the difference d_{bef} between the opinion and the hint before the exposure. According to the rules we stated earlier, d_{aft} will be distributed according to this density function: (16.2)

$$T(d_{aft}; d_{bef}, p_0, r, \gamma_0, \gamma_r) = \begin{cases} C(d_{aft}; 0, \gamma_0) & \text{with prob. } p_0 \\ C(d_{aft}; d_{bef}/r, \gamma_r) & \text{with prob. } 1 - p_0 \end{cases} \tag{16.2}$$

The transformation we just defined introduces four parameters:

- p_0, which is the probability that the old opinion is reset around $d = 0$; thus, with probability $1 - p_0$, the opinion shows a certain inertia; this resistance to change causes a shift toward the hint instead of a complete reset;
- r, the rescale factor quantifying the shift of resilient opinions;
- γ_0 and γ_r , the γ scale factors for the Cauchy distributions centered respectively in 0 and in d_{bef}/r introduced to add a realistic noise.

We used our data to infer the parameters of our model for Kassel, London, Turin and for the complete set of data. If we apply the transformation to phase I data, we get an estimation of phase III distances between opinions and hints. Then, to evaluate how good is the estimation, we use a two sample Kolmogorov-Smirnov two sided test. This kind of test gives as result the probability p_{val} that the hypothesis that the two samples are drawn from the same distribution cannot be rejected. Usually, a value below 5 % means that the hypothesis has to be rejected otherwise the hypothesis is likely to be true. If the p_{val} is around 10 % the two samples come from two distribution which are, in any case, very close. Above the 30 % the samples can be considered with a good degree of confidence as coming from the same distribution. We explored the space of parameters with 10 % steps and repeating the test 100 times to find the combinations with the highest p_{val} for Kassel, London, Turin and for the overall. These optimal combinations are reported in Table 16.1 with the relative results for the Kolmogorov-Smirnov test.

From the table seems that the reset of the opinion around the hint happens not so often. In London, for example, it is almost a secondary effect. In the best case, Turin, the reset seems to be there slightly more then in the half of the cases. We also reported in Fig. 16.15 an estimation of the APDs for phase III obtained by applying the transformation (16.2) with the optimal parameters combination to the data of phase I. The similarity between estimation and phase III real data is pretty clear.

It is very likely that Eq. (16.2) is not the real transformation of the opinion due to the subjects exposure to hints. We made strong assumptions and we reduced our data set to focus on the interesting part. Also, we are analyzing and modeling the phenomenon on a very narrow timescale (weeks) without knowing almost anything about the others (for example, if we consider months the dynamics could be potentially extremely different). Despite this considerations, the results we showed is novel, to our knowledge, and seem to point out with sufficient reliability that the

Table 16.1 Parameters combination with the highest p_{val} resulting from the Kolmogorov-Smirnov test

Dataset	p_0	r	γ_r	γ_0	$< p_{val} >$
Kassel	0.336	1.62	0.381	0.0138	0.192
London	0.147	1.90	0.100	0.030	0.267 (0.087)
Turin	0.583	1.56	0.304	0.300	0.417
Overall	0.204	1.767	0.28	0.015	0.262

Parameter space has been explored with 10 % steps and each configuration has been tested 100 times. The average p_{val} is reported. Some peaks in the tails for London compromised the test, causing as a result unsatisfying values for the parameters. We reduced the range in the most meaningful area, which is $(-1 : 4)$. We found the best parameters testing only this area, obtaining a remarkable result ($p_{val} = 27\,\%$). Then we made again the test reintroducing neglected data, obtaining a $p_{val} = 9\,\%$ which is still a satisfactory result

main ingredients are there. The model we referred to helped us to measure how our volunteers were influenced by the hints we gave them. We may now affirm with a certain degree of confidence that even when people do not trust completely the AS values, they still get influenced by them. Another way to see this is that, even if people do not reset their opinions, the space itself in which their opinions are arranged is deformed by the exposure to hints. Obviously these considerations are justified if the subjects consider the source of the hints as objective. In other cases, for example if volunteers are told that opinions come from other volunteers, completely different dynamics are expected to come into play.

16.5 Conclusions and Perspectives

Volunteer participation is crucial for the success of bottom-up monitoring campaigns, however most projects concerned with environmental monitoring concentrate still on the development of the technical tools necessary. In the EveryAware project we gave a different user-centric perspective though its large scale test cases for noise and air pollution.

For the noise case, several indicators have been derived from the objective versus subjective data submitted by users, leading to the main findings:

- Guessed levels of noise, compared to the measured ones, indicate that users learn to estimate the noise level after repeated usage of the application.
- Perception rating is shown to change in time, as users perform more measurements. Hence noisy environments are qualified as more hectic and less lovable by experienced users, compared to novices.

- An increase in the fraction of tags submitted by users was observed as these became more experienced. This suggests an increase in involvement and dedication with time. Together with the change in perception, this indicated an increase in awareness after repeated usage of the WideNoise application.

For air quality, objective measurements allowed for analysis of user interests during the challenge, as well as learning. Both coverage and pollution levels measured indicated a tendency to monitor familiar areas when this was not restricted, with a search for highly polluted spots. However, as users become more familiar with an area, the levels of pollution decrease in the data, a first indication of learning how to avoid high pollution levels. Subjective data, on the other hand, allowed for analysis of perceived pollution levels. Volunteers started with a strict categorization in polluted and non-polluted areas, where pollution in affected areas was overestimated. Through usage of the EveryAware sensor box, they however adjusted their image, decreasing overall pollution levels. This shows that involving volunteers in monitoring campaigns can help learning to build a more accurate perception of air quality issues.

By means of a web-based game, the inertia of citizens to change their opinion on the air quality level of the urban environment was estimated. Interestingly, citizens seem to be reluctant, in a statistical sense, to change their opinions that are typically of pessimistic character and stick to their personal feelings rather than to trust data stemming from official measures. We observed, anyway, that these data have a nontrivial effect on citizens opinions, deforming the very space in which opinion are arranged. This information can be of interest for stakeholders and decision makers in order to find new efficient ways to improve awareness.

To the authors knowledge, this is the first study where a throughout parallel investigation of objective and subjective data has been performed, hopefully boosting an increase in awareness toward environmental issues. Beside the value as a proof of concept, the EveryAware project also succeeded in providing meaningful insight about the awareness and opinion shift mechanisms.

Although initial signs of learning and increased awareness have been found already at this level, the usage of the application and evaluation of indicators such as those presented here will be continued in the future. Additionally, an in depth study of several data components is envisioned for future work, such as a semantic analysis of tags, which could give further important insight into both the motivation and opinion of users about their environment.

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Chapter 17
Opinion Dynamics: Models, Extensions and External Effects

Alina Sîrbu, Vittorio Loreto, Vito D.P. Servedio, and Francesca Tria

17.1 Introduction

The discovery of quantitative laws in the collective properties of a large number of people, as revealed for example by birth and death rates or crime statistics, was one of the factors pushing for the development of a science of statistics in the 19th century. It let many scientists and philosophers to call for some quantitative understanding on how such precise regularities arise out of the apparently erratic behaviour of single individuals. Hobbes, Laplace, Comte, Stuart Mill and many others shared, to a different extent, this line of thought (Ball 2004). Also, Majorana in his famous tenth article (Majorana 1942, 2005) pointed out the value of statistical laws for social sciences. Nevertheless, it is only in the past few years that the idea of approaching society in a quantitative way has changed from a philosophical

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declaration of principles to a concrete research effort involving a critical mass of scientists, above all physicists. The availability of new large databases as well as the appearance of brand new social phenomena (mostly related to the Internet world) have been instrumental for this change.

In social phenomena the basic constituents are humans, i.e., complex individuals who interact with a limited number of peers, usually negligible compared to the total number of people in the system. In spite of that, human societies are characterized by stunning global regularities (Buchanan 2007). We find transitions from disorder to order, like the spontaneous formation of a common language/culture or the emergence of consensus about a specific issue and there are examples of scaling and universality as well. These macroscopic phenomena naturally call for a statistical physics approach to social behaviour, i.e., the attempt to understand regularities at large scale as collective effects of the interaction among single individuals.

Human behaviour is governed by many aspects, related to social context, culture, law and other factors. Opinions and beliefs are at the basis of behaviour, and can be seen as the internal state of individuals that drives a certain action. We hold opinions about virtually everything surrounding us, hence understanding opinion formation and evolution is key to explaining human choices. Opinion formation is a complex process depending on the information that we collect from peers or other external sources, among which mass media are certainly the most predominant. Hence, understanding how these different forces interact can give insight into how complex non-trivial collective human behaviour emerges and how well formulated information may drive individuals toward a virtuous behaviour.

In the context of sustainability challenges, the cumulative sum of people's individual actions has an impact both on the local environment (e.g., local air or water quality, noise disturbance, local biodiversity, etc.) and at the global level (e.g., climate change, use of resources, etc.). It is thus important to shed light on the mechanisms through which citizen awareness of environmental issues can be enhanced, and this is in turn tightly related to the way citizens perceive their urban environment. In this perspective, models of opinion dynamics can be applied to investigate mechanisms driving citizens' environmental awareness. Very important in this sense is the effect of the information citizens are exposed to (Gargiulo et al. 2008), both coming from mass media and from more personalized information, expressly tailored on individuals. It is then crucial to consider different modelling approaches to opinion dynamics in order to have a clear outline of the state of the art and to learn from their principles.

Traditionally studied by social science, formation of opinions, as well as other social processes, have become increasingly appealing to scientists from other fields (Castellano et al. 2009a). A large amount of work is concentrated on building models of opinion dynamics, using tools borrowed from physics, mathematics and computer science. Typically, such models consider a finite number of connected agents each possessing opinions as variables, either discrete or continuous, and build rules to explain opinion changes, resulting from interactions either with peers or other sources. Although assumptions and simplifications are made in building such models, they have proven very useful in explaining many aspects of opinion formation, such as agreement, cluster formation, transitions between order (consensus) and disorder (fragmentation). These models can help to give insights on the dynamics of the opinion formation process and eventually to make predictions that can be tested and backed up by real data, in a virtuous loop where results from modelling and experiments can be integrated and can be used to open and shed light on new questions.

In the following, we provide a review of opinion dynamics models by classifying them according to the presence or not of external information, that is a mechanism mimicking a sort of mass media broadcast. In Sect. 17.2 no information is present, while in Sect. 17.3 the external information is taken into account as an immutable agent participating in the dynamics. Each of the above sections are further split according to the effective form of the opinion, which can be modelled either as a one dimensional vector or as a multidimensional vector. As a further classification, the vectors representing agent opinions can be either discrete, i.e., their components can assume a finite number of states, or continuous, i.e., with values in the domain of real numbers. A separate section, Sect. 17.2.3, is dedicated to a quick review of models coping with the formation and respect of social norms, a subject tightly connected to environmental issues and sustainability.

This work is by no means intended as an exhaustive review of methods, although efforts have been made to include as many contributions as possible.

17.2 Existing Models of Opinion Dynamics and Extensions

One of the first and most popular models adapted to opinion dynamics from physics (Galam and Moscovici 1991; Galam et al. 1982) is the Ising model (Baxter 2007). This can be thought of as an extremely simplified agent based model. In agent based models, individuals are considered as independent agents that communicate to each other and update their opinions according to a limited set of fixed rules. The interaction between agents may be carried on pairwise or in groups. Agents are connected by an underlying graph defining the topology of the system and the interactions are usually between nearest neighbours. Agents are endowed with opinions, that may be represented as a variable, or a set of variables, i.e. represented by a vector with given components, discrete (that can assume a set of predefined values), or continuous.

In the Ising model, each agent has one opinion represented as a spin, that can be up or down, determining a choice between two options. Spin couplings represent peer interactions and external information is the magnetic field. This may appear too reductive, thinking about the complexity of a person and of each individual position. Everyday life, however, indicates that people are sometimes confronted with a limited number of positions on a specific issue, which often are as few as two: right/left, Windows/Linux, buying/selling, etc. Further, despite its simplicity, this model is particularly attractive since it foresees a phase transition from an ordered to a disordered phase, related to the strength of the spins interaction (inverse temperature in the physics language).

Although an interesting approach, the Ising model can be too simple to interestingly account for the complexity of each individual position and of interactions between individuals. Hence, in the last decade, many other models have been designed [an extensive earlier review of these can be found in Castellano et al. (2009a)]. The aim of this chapter is to present some of these models and a selection of their latest developments.

17.2.1 One-Dimensional Models

17.2.1.1 Discrete Opinions

The Voter Model The voter model is one of the simplest models of opinion dynamics, originally introduced to analyse competition of species (Clifford and Sudbury 1973). The model has then been attracting a large amount of attention in the field of opinion dynamics, and its name stems from its application to electoral competitions (Holley and Liggett 1975). In this model, each agent in a population of N holds one of two discrete opinions, $s = \pm 1$, similar to the Ising model mentioned above. Agents are connected by an underlying graph defining the topology of the system. At each time step, a random agent i is selected along with one of its neighbours j and the agent takes the opinion of the neighbour (Fig. 17.1). Thus, while spins in the Ising model try to align with the majority of their neighbours, voter dynamics involve one neighbour only, hence the majority does not play a direct role, but is felt indirectly through peer interaction. This difference in the updating rule is reflected in the patterns generated in two-dimensional lattices (Fig. 17.2), where domains of agents with the same opinion grow but interfaces between

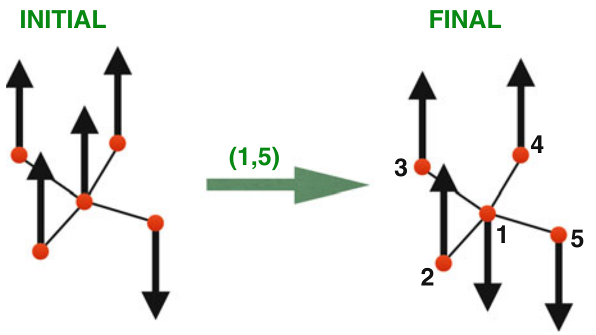

Fig. 17.1 Basic voter model interaction. Suppose that in the dynamical evolution of the model, which considers an interaction between an agent and one of its neighbours chosen at random, the agent number 1 was selected in the configuration of the *left* part of the figure. With probability 3/4 it will remain with a positive opinion since three of its neighbours have a positive opinion (the agents 2, 3, and 4), while with probability 1/4 it will change it since one of its neighbours has a negative opinion (the agent 5). In the example, the final state on the *right* refers to this latter event

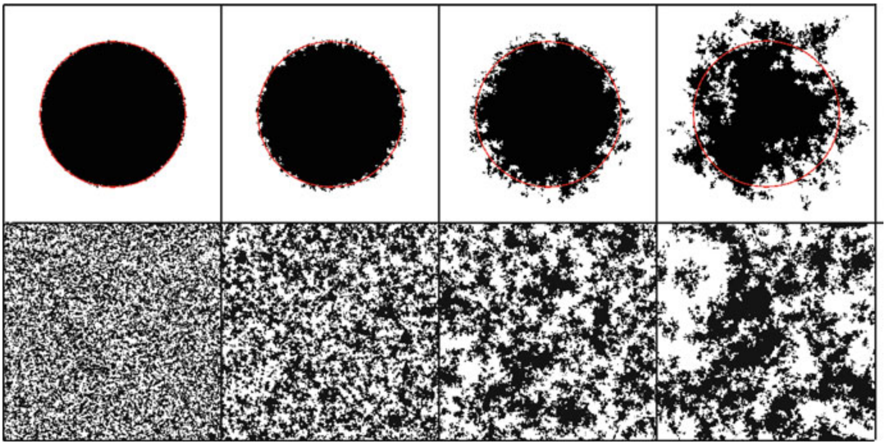

Fig. 17.2 Evolution of a two-dimensional voter model starting from a circle (*top*) or a fully disordered configuration (*bottom*). The *white* and *black* colours represent the positive and negative opinions respectively. From the *top* panel we can see how the *black* area remains practically constant during the dynamics and the original circular shape is destroyed. In physics, this signals a lack of surface tension. From Dornic et al. (2001)

different domains are very rough, unlike usual coarsening systems (Bray 1994). A generalized framework that encompasses different variations of voter dynamics has been introduced recently in Moretti et al. (2013a).

The voter model dynamics has been extensively studied when people are modelled as vertices in a d-dimensional hyper-cubic lattice. When considering a finite system, for any dimension d of the lattice, the voter dynamics leads to one of the two possible consensus states: each agent with the same opinion $s = 1$ or $s = -1$. The probability or reaching one or the other state depends on the initial state of the population. More interestingly, in an infinite system, a consensus state is reached only for dimensions $d \leq 2$ (Cox 1989). The time needed for a finite system to reach consensus is $T_N \sim N^2$ for $d = 1$, $T_N \sim N \ln N$ for $d = 2$, while $T_N \sim N$ for $d > 2$. Many generalization of the plain voter model can be considered. For instance, a level of confidence can be introduced for each opinion, determining the probability for an agent to change it. The confident voter model, where confidence is added to the agent state as a binary variable, converges to confident consensus in a time that grows as $\ln N$ on a complete graph, after crossing a mixed state of unsure agents (Volovik and Redner 2012). On a lattice, however, consensus time grows as a power law in N, with some configurations crossing a long-lived striped state.

The voter model in two dimension, with temperature, has been applied to explain opinion change in financial markets (Krause and Bornholdt 2012). The temperature (a type of noise) is associated to the nervousness of agents (fear). Through a feedback between the status of the entire agent population (market imbalance) and the temperature, nervousness becomes an evolving feature of the system. This passes through two types of metastable states, either long-lived striped configurations or shorter mean-field like states.

A recent development involves using power-law intervals between interactions (Takaguchi and Masuda 2011), as opposed to the nearest neighbours or exponential interval distribution in the original model. The analysis is performed on different network topologies, i.e. ring, complete graphs and regular random graphs. In general, power-law intervals slow down the convergence time, with small, if no differences, seen for the complete graphs, medium for regular random graphs and large for the ring. The same slowing down of dynamics is shown for update probabilities inversely proportional to the time since the last change of state or interaction, which in the end lead also to power-law inter-event time distributions (Fernández-Gracia et al. 2011, 2013). However, depending on how the probabilities are defined, so called 'endogenous' and 'exogenous' rules, full consensus can be reached or not, respectively.

In Benczik et al. (2009), the voter model is analysed on random networks, where links are rearranged in an adaptive manner, based on agent similarity (links with agents not sharing the opinion are dropped in favor of new connections to individuals having the same opinion). They show analytically that in finite systems consensus can be reached, while in infinite systems metastable states can persist for an infinitely long time. A different analysis on a *directed* adaptive network has been proposed in Zschaler et al. (2012) where link directionality is shown to induce an early fragmentation in the population.

A non-linear extension of the model is introduced in Yang et al. (2011). This allows agents to select their opinion based on their neighbours using a parameter α which controls the herding effect, i.e., the inclination of individuals to behave collectively as a whole. The probability that an agent adopts opinion $+1$ is

$$P(+1) = \frac{n_+^\alpha}{n_+^\alpha + n_-^\alpha}, \tag{17.1}$$

where n_+ (n_-) is the number of neighbours holding an opinion $+1$ (-1). For $\alpha = 1$ the original voter model is retrieved, while for large α a model similar to the majority rule (next paragraph) is obtained. Convergence time is analysed depending on α, and it is shown that a minimum is obtained for moderate values of α. For extremely low values, large clusters form slowly, while for very large values, large opinion clusters take long to merge. This indicates that in order to accelerate consensus, the local majority opinion should not be strictly followed, but this should be followed in a moderate way. The optimal α decreases with system size. This holds for a few network types analysed, i.e. regular lattices, Erdos-Renyi random graphs, scale-free and small-world networks. For the complex networks, the minimum α is also shown to increase with the network connectivity (average degree of the nodes).

Several other studies of non-linear dependence of an agent's opinion on the neighbours exist (Schweitzer and Behera 2009; Tanabe and Masuda 2013). The introduction of 'contrarians' has been studied in Tanabe and Masuda (2013), with three types of stable states obtained: (1) coexistence of the two opinions with equal fractions, (2) adoption of one opinion by contrarians and the other by the rest of the agents or (3) a limit cycle. Zealots have been shown to prevent consensus or robust majorities even when they are in small proportion (Mobilia et al. 2007), with a Gaussian distribution of the magnetization of the system when a small equal number of zealots are added for each opinion.

In Fotouhi and Rabbat (2013), the voter model with popularity bias is analysed. Here, the probability of a node to choose a particular state is not only based on the states of the neighbours, but also on their connectivity. The system is shown to reach consensus in a time $T \sim [\ln N]^2$, faster than the original voter model. When confidence is introduced, i.e. the probability of a state depends also on the current state of the agent, convergence to unanimity is slower. Irreversibility is also analysed, by making state $+1$ fixed, i.e. once agents reach this opinion they remain in that state. This is shown to converge to consensus on opinion $+1$ in logarithmic time.

Various other generalizations of the model have been proposed in the last years. An extension to three opinions has been developed in Mobilia (2011), where a third 'centrist' opinion (0) was introduced, as standing in the middle of the two 'extreme' opinions ± 1. Transitions from an extreme to the neutral opinion are governed by a parameter q measuring the bias towards extremism, with interactions between extremists impossible (constrained voter model). The authors show that polarization is favored for $q > 0$, however there is always a finite probability for consensus, while in the case of $q < 0$ consensus is more probable. Addition of centrist zealots (centrists who preserve their opinion) changes the system behaviour in that a large fraction of centrist zealots generates consensus on the neutral opinion (Mobilia 2013). A small zealot fraction leads to mixed populations, where centrists coexist with either both extremist types (when the two are equally persuasive) or with the most persuasive one.

Strategic voting introduced in the three-state voter model (Volovik et al. 2009) can reproduce patterns seen in real voting data, where two parties have similar votes and compete for the majority while the third party remains a minority over years. Stochastic effects can, however, interchange one majority party with the minority one, on a time scale growing exponentially with the size of the population, which has also been observed in real elections.

Kinetic interaction rules for the three state model (with states $o_i \in \pm 1, 0$) have been analysed in Crokidakis and Anteneodo (2012), where agents were influenced by two terms, a self conviction term and a peer effect term:

$$o_i(t+1) = C_i o_i(t) + u_{ij} o_j(t) \tag{17.2}$$

Peer interactions could be positive or negative ($u_{ij} \in \pm 1$) while convictions could be positive, negative or missing ($C_i \in \pm 1, 0$). The probability distributions for these values determined the point of a transition between an ordered and a disordered state, with negative interactions leading to increased disorder. Real valued convictions that controlled which of the two peers will take the other's opinion and conviction were introduced in (Crokidakis 2013). Noise was added to the system in the form of an instantaneous adoption of opinion 0 by an agent in the neighbourhood of the interacting pair, with probability p. Stationary states were obtained for all noise levels, with one of the ± 1 opinions disappearing and the other coexisting with the null opinion (undecided). Very high noise led to states where most agents were undecided, while consensus states were only obtained in the noiseless case ($p = 0$). An external effect was also introduced, which affected again the neighbourhood of the interacting pair. This was shown to decrease the number of undecided agents in the population. Also, a large strength of the external effect was shown to decrease its success.

The voter model with arbitrary number of options was also analysed on co-evolving networks (Malik and Mucha 2013). An agent could either convince a neighbour of their opinion or disconnect and rewire to another agent. This rewiring was performed in a preferential manner, i.e. agents close in the network and flexible towards one another were selected more often. The probability distribution determining how often an agent accepted the other's opinion accounted for the 'social environment', while preferential rewiring for 'social clustering'. Depending on the flexibility of the social environment, two system states were observed. A flexible society evolved to a large connected component of agents sharing the same opinion ('hegemonic consensus'), with a small-world network structure. An inflexible society resulted in multiple components disconnected from the others, a so called 'segregated consensus'. Within each component, agents shared the same opinion, which could be different from the other components.

The Majority Rule (MR) Model The MR model was first proposed to describe public debates (Galam 2002). Agents take discrete opinions ± 1 and can interact with all other agents (complete graph). At each time step a group of r agents is selected randomly and they all take the majority opinion within the group, as exemplified in Fig. 17.3. The group size can be fixed or taken at each time step from a specific distribution. If r is odd, then the majority opinion is always defined, however if r is even there could be tied situations. To select a prevailing opinion in this case, one possibility is to introduce a bias in favor of one opinion, say $+1$. This idea is inspired by the concept of social inertia (Friedman and Friedman 1984). The

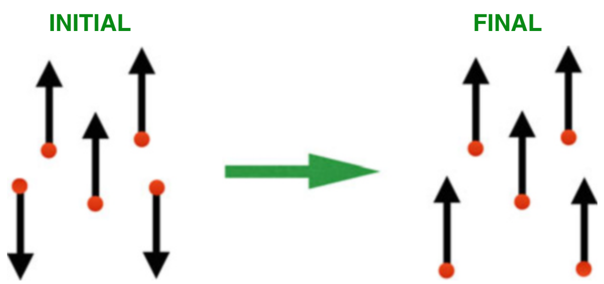

Fig. 17.3 Majority Rule model. The majority opinion inside a discussion group (here of size five) is taken by all agents

MR model with opinion bias was originally applied to describe hierarchical voting in society (Galam 1986, 1990, 1999, 2000) with the discussion recently extended to three discrete choices for hierarchical voting (Galam 2013).

If we define p_+^0 to be the initial fraction of agents with the opinion $+1$, and we allow the system to evolve, all agents will have opinion $+1$ (-1) if $p_+^0 > p_c$ ($p_+^0 < p_c$). If r is odd, $p_c(r) = 1/2$, due to the symmetry of the two opinions. If r is even, $p_c < 1/2$, i.e., the favored opinion will eventually be adopted by the entire population, even if initially shared by a minority of agents. To reach the consensus, the number of updates per agent scales like $\log N$ (Tessone et al. 2004). Under power-law noise, the system relaxes in a state with constant magnetization if the noise amplitude is under a threshold, while for higher amplitude the magnetization tends to zero (Stauffer and Kulakowski 2008).

A full review of extensions and application of the MR model can be found in Galam (2008a). Recent extensions have been used to explain results of public debates on different issues such as global warming, evolution theory, H1N1 pandemic (Galam 2010). These include two types of agents, floater and inflexible, where inflexible agents do not change their opinion. It is shown that, for the case where not enough scientific data is available, the inflexible agents are those that drive the result of the debate. Hence, a strategy for winning a debate is the acquisition of as many inflexible agents as possible. Also, the analyses indicate that a fair discourse in a public debate will most likely lead to losing, while exaggerated claims are very useful for winning. Similar results are presented in Galam (2008), where contrarians, i.e. agents who take the minority opinion of a group, are also introduced. The effect of introducing both contrarians and inflexible agents is discussed in Jacobs and Galam (2008), and results from the previous studies confirmed.

The same issue of public debates has been analysed with a different variation of the model (Galam 2010). Here, collective beliefs are introduced as an individual bias to select one or the other opinion, in case of a tie in voting. Here only pair interactions are analysed. The study shows that collective beliefs are very important in determining the results of the debate, and again, a winning strategy is acquiring inflexible agents, which may mean using overstated or exaggerated statements. A similar model has been also applied to explain the formation of bubble crashes in the financial market (Galam 2011). Agents decide to sell or buy depending on the majority rule and the collective beliefs in case of tie. The model shows that it is the collective beliefs that determine a discrepancy between the real and the market value of an asset, which in turn generates crashes. If the collective beliefs are balanced, or ties do not appear (by using odd-sized groups), these crashes do not appear.

Two model extensions with independent agents and collective opinions have been introduced in Wu and Chen (2008). Here, the MR model is applied with probability $1-q$, while with probability q the agent either chooses one random option (extension 1) or follows the collective opinion (model 2). The authors show that, in both cases, there exists a threshold for q under which complete consensus is obtained.

The majority rule model has been analytically studied on hypergraphs, with a version entitled 'spatial majority rule model' (Lanchier and Neufer 2013). Hyperedges consisting of n vertices were used to define social groups. Agents on a hyperedge simultaneously changed their opinion to that of the majority on the same hyperedge, while ties resulted in adoption of opinion $+1$. The system was shown to converge to a majority of $+1$ for n even and to cluster for n odd, even with an infinite number of hyperedges.

A model sharing similarities to the MR model above is the non-consensus opinion (NCO) model and its extensions (Li et al. 2013). These introduce the self opinion in the majority rule, with or without a weight, and the system is shown to achieve stable states where the two competing opinions coexist, on different network types, including coupled networks.

An application of a similar model, entitled majority vote model, to model tax evasion dynamics is presented in Lima (2012a,b). Here, $+1$ represents and honest individual, while -1 an individual evading tax. Individuals change their opinion with a probability which depends on the average of all of their neighbours:

$$P(\text{`flip'}) = \frac{1}{2}\left[1 - \sigma_i(1-2q)\,\text{sign}(\sum_{n\in N(i)} \sigma_n)\right] \tag{17.3}$$

Here, σ_i is the current opinion of agent i, $N(i)$ is the set of neighbours of i, while q is a noise parameter. In the model an audit procedure is also introduced. When an agent chooses to evade taxes, a punishment is imposed with probability p, consisting in forcing the agent to be honest for a number of k population updates. Different network topologies are analysed: square lattice, Barabasi-Albert and Honisch-Stauffer. Numerical results show that without punishment, tax evasion fluctuates, reaching at times very high levels. The introduction of audit, even at very low levels, is shown to reduce drastically the percentage of agents choosing to avoid tax. Similar results had been obtained previously using the Ising model (Zaklan et al. 2008).

The majority vote model has also been analysed with heterogeneous agents (Lima 2013), i.e. the parameter q above is replaced by q_i, characteristic to each agent. These new parameters are drawn randomly at the beginning of the simulations from an interval $[0, q]$. Critical exponents are estimated using both analytic and numerical tools.

Social Impact and the Sznajd Model Interactions and opinion formation, with their complex underlying features, have been long analysed by social scientists, and theories devised to explain them. One example is social impact theory (Latane 1981), which states that the impact of a group of people on an individual depends mainly on three factors: their number, their distance and their strength. A first application of this theory to build a dynamical model of opinion formation has been introduced in Lewenstein et al. (1992) and Nowak and Lewenstein (1996). This uses cellular automata to model individuals which hold one of two opinion values $\sigma_i = \pm 1$. They are placed within a network, which accounts for the spatial factor, i.e. the distance d between individuals. Individual strength is represented by two variables: persuasiveness (how much is an agent able to influence another) and supportiveness (how much an agent supports the opinion they hold in their neighbourhood). Social impact on individual i is then computed as a weighted sum of the persuasiveness of other agents holding a different opinion and the supportiveness of agents holding the same opinion :

$$I_i = I_p \left(\sum_j \frac{t(p_j)}{g(d_{ij})} (1 - \sigma_i \sigma_j) \right) - I_s \left(\sum_j \frac{t(s_j)}{g(d_{ij})} (1 + \sigma_i \sigma_j) \right) \tag{17.4}$$

Here d_{ij} is the distance between agents i and j (which can be defined depending on the network type used), $g()$ is a decreasing function of d_{ij} and $t()$ is a strength scaling function. Thus, the updating rule for opinion of agent i is:

$$\sigma_i' = -\text{sign}(\sigma_i I_i + h) \tag{17.5}$$

where h is a noise factor. The model was shown to lead to spatially localized opinion clusters, where minority clusters are facilitated by the existence of strong individuals supporting the weaker ones. This holds for a variety of social network topologies: fully connected graph, hierarchical networks, strongly diluted networks and Euclidean space.

Another recent model employing the theory of social impact is the Sznajd model (Sznajd-Weron and Sznajd 2001). This is a variant of spin model, on a one dimensional lattice, that takes into account the fact that a group of individuals with the same opinion can influence their neighbours more than one single individual. The proximity factor is also taken into account, by considering neighbouring agents on the lattice. However, the strength of individuals, a third factor mentioned in the theory of social impact, is not present. Each agent has an opinion $\sigma_i = \pm 1$. At each time step, a pair of neighbouring agents is selected and, if their opinion coincides, all their neighbours take that opinion. Otherwise, the neighbours take contrasting opinions (Fig. 17.4). The model has been shown to converge to one of the two

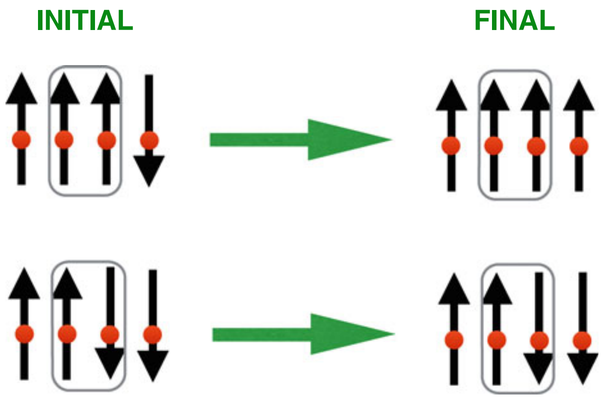

Fig. 17.4 Sznajd model. A pair of neighbouring agents with the same opinion convince all their neighbours (*top*), while they have no influence if they disagree (*bottom*)

agreeing stationary states, depending on the initial density of up-spins (transition at 50 % density). Versions on a two dimensional lattice have also been studied, with four neighbours (a plaquette) having to agree in order to influence their other eight neighbours (Stauffer et al. 2000). Extensions to a third option (centrist/indifferent) have been also studied (Baker and Hague 2008; Malarz and Kulakowski 2009).

A different extension is the introduction of "social temperature" (Lama et al. 2005). Here the original rules of the Sznajd model are applied with probability p, i.e. all neighbours take the opinion value of the plaquette, in case they agree. With probability $1 - p$ the agents take the opposite value than dictated by the original Sznajd rules. This results in disagreement by some individuals who choose to be or not to be contrarians at each update. Importantly, disagreement is not a fixed attribute of the individuals, but varies in time. It was shown that over a critical threshold for p, the behaviour of the original model is conserved, i.e. all individuals agree to one opinion. Under this threshold the system remains in a disordered state with magnetization (defined as $\sum_{i=1}^{N} \sigma_i/N$) close to 0.

A recent study of disagreement in the Sznajd model in one dimension is Kondrat and Sznajd-Weron (2010), where conformist (agreement) and anti-conformist (disagreement) reactions appear. Specifically, the model is introduced a parameter p which defines the probability that, when two neighbours hold the same opinion, a third neighbour, that previously held the same opinion, will take the opposite position. If the third neighbour did not share the opinion of the initial pair, then they take that opinion, as in the original Sznajd model. It is shown that for low anti-conformity, consensus can be reached, and spontaneous shifts in the entire population between ± 1 appear. On the other hand, high anti-conformity results in oscillations of the magnetization level around 0, without reaching ± 1. The same model has been applied on complete graphs (Nyczka et al. 2012a). Here, it was shown (both numerically and analytically) that the reorientations for low anti-conformism (p) appear now between two magnetization states $\pm m$ instead of ± 1.

Agent independence (as opposed to disagreement) is studied in Sznajd-Weron et al. (2011). Independence means that a neighbouring agent can choose not to follow an agreeing plaquette, with probability p. In this case, they can flip their opinion with probability f, described as agent flexibility. The model is analysed on one and two-dimensional lattices and on a complete graph. Independence is shown to favor coexistence of the two opinions in the society, with the majority being larger for small independence levels (p).

The Sznajd model with reputation, on a 2-D lattice, has been also analysed (Crokidakis and Oliveira 2011), where each agent has a reputation value associated. The agent plaquette can influence the neighbours, with probability p, only if they agree and they have an average reputation larger than the neighbours. Reputations also evolve, i.e. they increase if the plaquette influences a neighbour and decrease otherwise. The model is shown to lose the phase transition for $p < p_c \sim 0.69$, when some agents preserve a non-majoritary opinion.

An analysis of the Sznajd model on an Erdos-Renyi random graph with enhanced clustering is presented in Malarz and Kulakowski (2008), where the model is shown to not reach full consensus, unlike the original model. The connection of a modified version of the model, which includes bounded confidence and multiple discrete opinions, with graph theory is discussed in Timpanaro and Prado (2012).

The model has been also included in a study of two competing processes, one following Sznajd and the other Voter dynamics (Rybak and Kulakowski 2013). Agents are connected by a Watts-Strogatz small-world network, and can be in two states, either S or D. At each time step, a random agent is selected. If it is in state S, it turns a random neighbour from state D to state S. If it is in state D, with probability p select another random neighbour in state D, if it exists, and turn all of their neighbours into state D as well. The system is shown to switch between full consensus on S to full consensus on D depending on p, when the clustering coefficient is low. However as the clustering coefficient increases, the opinion S is facilitated.

The q-Voter Model In Castellano et al. (2009) the non-linear q-voter model is introduced, as a generalization of discrete opinion models. Here, N individuals in a fully connected network, hold an opinion ± 1. At each time step, a set of q neighbours are chosen and, if they agree, they influence one neighbour chosen at random, i.e. this agent copies the opinion of the group. If the group does not agree, the agent flips its opinion with probability ε. The voter and Sznajd models and many of their extensions are special cases of this more recent model. Analytic results for $q \leq 3$ validate the numerical results obtained for the special case models, with transitions from a ordered phase (small ε) to a disordered one (large ε). For $q > 3$, a new type of transition between the two phases appears, which consist of passing through an intermediate regime where the final state depends on the initial condition. The model has been also studied on heterogeneous mean field and random regular networks (Moretti et al. 2013b), where the intermediate regime is shown to disappear in the case $q > 3$, behaviour qualitatively similar to that obtained on a lattice.

In Nyczka et al. (2012) the q-voter model is analysed for non-conformity and anti-conformity with the aim to compare the two types of dynamics. Nonconformity implies that some agents, regardless of what the influencing group's opinion is, will decide to flip their opinion with probability p. Anti-conformity means that some agents will not follow the opinion of the group, but the opposite one, with probability p. The comparison shows important difference between the two types of dynamics, although they appear to be very similar. In the case of anti-conformism, the critical value p_c for the order-disorder phase transition is shown to increase with q, while for non-conformism, this decreases with q.

Other Approaches Binary opinions have been analysed on interdependent networks (Halu et al. 2013). Two networks were considered, each corresponding to one party running for elections. Agents were part of both networks, and chose whether to vote for one of the two parties or none based on interactions on the two different networks. A simulated annealing algorithm was used to minimize the value of a Hamiltonian that counted the conflicting connections in both networks. The method showed that the most connected network wins the elections, however a small minority of committed agents can reverse the outcome.

17.2.1.2 Continuous Opinions

Deffuant-Weisbuch The Deffuant-Weisbuch model (Deffuant et al. 2000) uses a continuous opinion space, where each individual out of a population of N can take an opinion value $x_i \in [-1, 1]$. Two individuals interact if their opinions are close enough, i.e. $|x_i - x_j| < d$, with d a bounded confidence parameter. In this case, they get closer to one another by an amount determined by the difference between them and a convergence parameter μ:

$$x_i = x_i + \mu(x_j - x_i). \tag{17.6}$$

The population was shown to display convergence to one or more clusters (c) depending on the value of the bounded confidence parameter ($c \approx \lfloor \frac{1}{2d} \rfloor$ (Carletti et al. 2006)). Parameters μ and N (population size) determine the convergence speed and the width of the distribution of final opinions. A feature typical to the clusters obtained by this model is the emergence of small extreme clusters (Lorenz 2005).

The Deffuant-Weisbuch model has received a lot of attention in the literature [see (Lorenz 2007a) for a previous review], with several recent analyses and extensions. For instance, Weisbuch et al. (2002) discusses heterogeneous and adaptive confidence thresholds on 2D lattices, while in Jager and Amblard (2005) the model has been extended to include disagreement in order to better describe the Social Judgment Theory (Griffin 2012; Sherif et al. 1965). In Gomez-Serrano et al. (2012), analytical results are provided, showing that in the limit of time $t \to \infty$, the population forms a set of clusters too far apart to interact, at a distance larger than d, after which agents in individual clusters converge to the cluster's barycentre. When $N \to \infty$, the opinion evolution is shown to be equivalent to a nonlinear Markov process, which proves the "propagation of chaos" for the system. This means that, as the system becomes infinite in size, an opinion evolves under the influence of opinions selected independently from the opinion process, at a rate given by the limit of the rate at which agents interact in the finite system. The initial condition and noise ('free will') were shown to have large effects on the number of clusters obtained (Carro et al. 2013). Specifically, segregated initial conditions were shown to have difficulties achieving consensus, while initial cohesion resulted in convergence to one cluster. This effect can be partially removed by noise.

The original model is based on agreement dynamics, i.e. if individuals are too different, they do not interact. However, disagreement dynamics are well known to appear in real situations (Huckfeldt et al. 2004). Hence, in Kurmyshev et al. (2011), partial contrarians were included, which are agents that can disagree (i.e. change their opinion in the opposite direction) with individuals that think differently. The society is mixed with the two types of agents, and it is shown that dynamics change depending on the amount of individuals that can disagree. Depending on the value of the bounded confidence parameter, one, two or more clusters can be observed, similar to the original Deffuant-Weisbuch, but bifurcation patterns are different. For a large number of contrarians, the number of clusters decreases as the confidence increases, but clusters become more different. For a smaller number of contrarians, on the other hand, clusters also become closer when they are fewer. This shows that contrarians favor a more determined fragmentation, i.e. not only the number of clusters, but also the distance between clusters increases. Also, the new type of agents increases the time required to reach a final frozen state. A similar approach can be found in Huet et al. (2008), where the 2-D Deffuant model with disagreement is analysed, and shown to favor extremist clusters. The model with partial contrarians presented in Kurmyshev et al. (2011) has also been extended to include opinion leaders (Kurmyshev and Juárez 2013). These were represented as individuals with high connectivity and fixed opinion, while the rest of the individuals were connected by a small-world network. Depending on the bounded confidence (tolerance) of the leaders, their connectivity and opinion, different patterns were shown to emerge in the system. While for a society without contrarians, tolerant leaders are more successful, in a society with contrarians this model suggests that intolerant leaders are better able to impose their views.

Noise or opinion drift has been also analysed for this model. Earlier studies introduced noise as the possibility of an agent to switch to a random opinion, with a certain probability (Pineda et al. 2009). This resulted in a transition between a disordered state, for larger noise, to formation of opinion clusters. These clusters however differed from the original model in that opinions included was not exactly the same, but a spread was visible. Also, in certain situations, spontaneous transitions between different cluster configurations were observed. Similar results were reported by Nyczka (2011), where interactions were slightly changed so that an individual can influence more neighbours at a time. The study (Pineda et al. 2011) allows individuals to change their opinion in an interval centred around the previous one, instead of the entire possible range. This type of dynamics is addressed as diffusion here. The width of the diffusion interval determines how the system behaves, with a low diffusion favoring consensus, with a cluster which changes its centre of mass due to continuous oscillations. Large diffusion produces clusters and fluctuation patterns similar to the previous studies.

A different extension of the model is to consider the bounded confidence parameter as an attribute of the individuals, hence different for each. In Lorenz (2010) heterogeneous bounds of confidence are shown to enhance the chance for consensus, since close-minded individuals can be influenced by the more open-minded ones (this extension has been also applied to the Hegselmann-Krause model described in the next section). On the same lines, Gargiulo and Mazzoni (2008) devises a method of computing the bounded confidence threshold based on the current individual opinion, to obtain less confidence for extremists:

$$d_i = 1 - \alpha |x_i|, \tag{17.7}$$

where α controls the tolerance rate. The update rule is also changed so that extremists change their opinion less:

$$x_i = x_i + d_i(x_j - x_i)/2 \tag{17.8}$$

Additionally, the social network is determined at the beginning depending on how extreme are individual opinions (extremists interact only with similar individuals, while moderated individuals can interact with a wider range, based on a segregation parameter β). Under these new conditions, it is shown that opinions converge to one large cluster when α is very small or β is very large, with some small coexisting extreme clusters, while pluralism is conserved only when extremist clusters are connected enough to continue to communicate to others (large α and β).

Further, in Gandica et al. (2010) an analysis of the Deffuant-Weisbuch model on scale free directed social networks is presented, and the average number of final opinions is shown to be larger, when compared to undirected networks, for high bounded confidence parameter d and smaller for low d. Also, an analysis on an adaptive network is presented in Gargiulo and Huet (2010).

The Deffuant model with bias has been analysed in Perony et al. (2012), in a setting reaching for consensus. The bias has been introduced in the interaction rule, where changes in individuals were larger towards the bias. Also, an hierarchical interaction structure was imposed, by adding a second stage to the classical Deffuant model: once clusters are stable, each of them defines a representative, and these interact further with no bounded confidence imposed. This approach always leads to consensus, and it was shown that the effect of strong biases is reduced by using the hierarchical consensus, compared to the original dynamics. For lower bias however it was shown to be detrimental.

Coupling of this model with a public goods game has been studied in Gargiulo and Ramasco (2012). Here, the 'Tragedy of commons' game has been enhanced by a social interaction component. Specifically, after each round of the game, a random agent interacts with a neighbour using the update rule of the Deffuant model, if the neighbour had at least the same payoff in the last round. The opinion value so obtained represents the probability that each agent chooses one of the two possible strategies in the next round (cooperate or defect). The authors show that cooperation can be increased by adding the social component, and that the system behaviour does not change with the social network topology.

The Hegselmann-Krause (HK) Model

A similar model to that presented in the previous section is the HK model (Hegselmann and Krause 2002). Opinions take values in a continuous interval, and bounded confidence limits the interaction of agent i holding opinion x_i to neighbours with opinions in $[x_i - \varepsilon, x_i + \varepsilon]$, where ε is the uncertainty. The update rule, however, differs, so that agents interact with all compatible neighbours at the same time:

$$x_i(t+1) = \frac{\sum_{j:|x_i(t)-x_j(t)|<\varepsilon} a_{ij} x_j(t)}{\sum_{j:|x_i(t)-x_j(t)|<\varepsilon} a_{ij}}, \tag{17.9}$$

where a_{ij} is the adjacency matrix of the graph. So, agent i takes the average opinion of its compatible neighbours. Hence, this model is more suitable to model situations like formal meetings, where interaction appears in large groups, while Deffuant is better suited for pairwise interaction within large populations.

The model has been proven to converge in polynomial time, with at least a quadratic number of steps required (Bhattacharyya et al. 2013). It is completely defined by the bounden confidence parameter ε, facilitating its analysis. The agent population groups into clusters as the system evolves, similar to the Deffuant model, with the number of final opinion clusters decreasing if ε increases. For ε above some threshold ε_c, there can only be one cluster. The convergence to one cluster can be very slow due to appearance of isolated individuals in the middle of the opinion spectrum. Recently, an in-depth analysis of clustering patterns, depending on ε has been performed (Slanina 2010), and it was shown that there are genuine dynamical phase transitions between k and $k + 1$ clusters, and that around critical values of ε, the dynamics slows down. The similarities and differences between the HK and the Deffuant method in the previous section have been discussed in Lorenz (2005, 2007b), by formulating the two systems as Markov Chains. This meant considering the distribution of an infinite population of agents on a finite number of opinion classes. The cluster patterns of the two models have been proven to be intrinsic to the dynamics, and the fixed points identical for the two models.

A further study on the clustering patterns (Blondel et al. 2009) proved analytically that the population in the HK model with real opinions (not restricted to interval [0,1], but to [0,L]) and $\varepsilon = 1$ converges always to clusters that are at distance larger than 1, and provided calculation of lower bounds of inter-cluster distance both for finite size and a continuum of agents. The continuum version of the model considers individuals indexed by the real interval $I = [0, 1]$, which have opinions in interval $[0, L]$. Hence, for $\alpha \in [0, 1]$, $x_t(\alpha) \in [0, L]$ is the opinion of individual α at time t. Defining $C_x = \{(\alpha, \beta) \in I^2/|x(\alpha) - x(\beta)| < 1\}$, the update rule becomes:

$$x_{t+1}(\alpha) = \frac{\int_{\beta:(\alpha,\beta)\in C_{x_t}} x_t(\beta)d\beta}{\int_{\beta:(\alpha,\beta)\in C_{x_t}} d\beta} \tag{17.10}$$

Proofs are given that during convergence, there is always a finite density of individuals between two clusters, which indicates that the model can never converge to an unstable equilibrium. This model is shown to be the limit of the original HK model, as the population size goes to infinity. Recently, the same authors have proved similar behaviour for a continuous-time symmetric version of the model, with both discrete and a continuum of agents (Blondel et al. 2010).

Additionally, in Mirtabatabaei and Bullo (2011), an analysis of the interaction network is performed. This is dynamic in the HK model, and evolves with the agent opinions, to reach a steady state where the network converges to a fixed topology, as demonstrated by Mirtabatabaei and Bullo (2011). A different approach of devising analytical results for this model is by looking at the evolution of the distribution of opinions in the population, i.e. Eulerian HK model (Mirtabatabaei et al. 2012).

The heterogeneous version of the model, i.e. where the bounds ε are different for different agents, is analysed in Mirtabatabaei and Bullo (2012) and shown to display pseudo-stable configurations, where part of the population is static. This model is compared with another version employing bounded *influence* instead of bounded *confidence*. Bounded *influence* states that an individual i is affected by an individual j if i is in the influence area of j, i.e., $(|x_i - x_i| < \varepsilon_j)$. This system was shown to converge faster that the original version.

Other Models Apart from the above mentioned models, several other agent-based approaches have been introduced, which share similarities with the Deffuant and Hegselmann-Krause models. In Mas et al. (2010) a model of continuous opinions, balancing individualization versus social integration, with adaptive noise, is introduced. Depending on the noise and individualization levels, three states of the population can be obtained: consensus, individualism or preserved pluralism.

A different agent based modelling approach is Mavrodiev et al. (2012), where the effect of social influence on the wisdom of crowds is analysed. The concept of wisdom of crowds means that the aggregated opinion of a group is closer to the truth than individual agent opinions. In this model, agents hold one continuous opinion on an issue, and interaction is modeled as the effect of the average opinion of peers. Simulation results show that the effect of social influence depends on the initial condition. Specifically, if the initial individual opinions are far from the truth, interaction has a beneficial effect, however, if they start close to the truth, social influence results in a decrease of the wisdom of crowds.

In Acemoglu and Como (2010), a continuous opinion model with Poissonian interaction intervals and stubborn agents is introduced. These agents do not change their opinion. The model was shown to generate continuous opinion fluctuation and disagreement in the population, i.e. consensus is never reached.

Biased assimilation is analysed in Dandekar et al. (2013), building upon a continuous opinion model where agents update their opinion by performing a weighted average over their neighbours. Biased assimilation means that agents tend to reinforce/extremize their opinion when shown inconclusive information about an issue. This was introduced in the model by adding a further term in the weighting procedure which depends on the current opinion of the agent. The authors show analytically that, although the model without biased assimilation does not produce polarization, even when homophily is introduced through the weights, the introduction of the new component allows for polarization to be observed.

An approach different from those presented until now uses the Kuramoto model of coupled oscillators to describe opinion formation (Hong and Strogatz 2011). Two types of oscillators are considered, corresponding to agents which agree or disagree to others. Disagreeing oscillators are negatively coupled to the mean field. The paper shows that, even when oscillators have the same frequency, the introduction of disagreement leads to appearance of opposite clusters, travelling waves or complete incoherence.

Models based on kinetic exchange have also been proposed for opinion dynamics (Lallouache et al. 2010a,b). Here an agent holds a continuous opinion $x_i \in [-1, 1]$ and a conviction $\lambda_i \in [0, 1]$. Upon interaction, two agents i and j change their opinions depending on their own and the peer's conviction:

$$x_i(t+1) = \lambda_i x_i(t) + \varepsilon \lambda_j x_j(t) \tag{17.11}$$

$$x_j(t+1) = \lambda_j x_j(t) + \varepsilon' \lambda_i x_i(t) \tag{17.12}$$

For the heterogeneous case ($\lambda_i < \lambda$), the model was shown to display breaking of symmetry for $\lambda > \lambda_c = 2/3$. That is, for values under λ_c, the system maintains an average opinion of 0, while over that, the average opinion is non null. Detailed analytic studies followed in Biswas et al. (2011, 2012).

The kinetic model has been extended to differentiate between a person's conviction (λ_i) and their ability to influence others (μ_i) (Sen 2011). Hence the update rule becomes

$$x_i(t+1) = \lambda_i x_i(t) + \varepsilon \mu_j x_j(t) \tag{17.13}$$

The model was shown to display the same symmetry breaking with a boundary set by $\lambda = 1 + \frac{\mu}{2}$. Several other extensions have been recently proposed, such as introduction of positive and negative interactions (disagreement with probability p) Biswas et al. (2012), or of bounded confidence Sen (2012).

The information accumulation system (IAS) model uses the concepts of volatility (Δ) and diffusivity (ω) for opinion dynamics Shin and Lorenz (2010). The opinion o_i stands in interval $[-1, 1]$ and evolves as

$$o_i^{t+1} = (1 - \Delta) o_i^t + \sum_{j \in N_i} \omega \, o_j^t (1 - |o_i^t|) \tag{17.14}$$

with N_i the set of neighbours of i. The model has been employed to analyse a system of two communities connected by inter-community links, which start with two different opinions on a subject (Shin and Lorenz 2010). The question is under what circumstances the two communities can converge to the same opinion. The maximum ratio between inter- and intra-community links for which the two communities do not show consensus is analysed, and shown to increase as the intra-community connectivity increases. This means that although general connectivity might increase, that does not mean the two communities will converge to one opinion, since the increase in inter-community links should be higher for consensus to emerge.

17.2.1.3 Hybrid Models

The CODA Model Continuous Opinions and Discrete Actions (CODA) are used to model the degree of acquiring a certain discrete opinion. The original model (Martins 2008) considered two opinions $+1$ and -1. Individuals are represented on a square lattice by a continuous probability p_i showing the extent of agreement to opinion $+1$ (with $1 - p_i$ corresponding to -1). Based on this, the choice of the discrete opinion σ_i is made, using a hard threshold:

$$\sigma_i = \mathrm{sign}\,(p_i - 1/2). \tag{17.15}$$

Individuals see only the discrete opinions of others, σ_i, and change the corresponding p_i based on their neighbours, using a Bayesian update rule, which favors agreement to the neighbours. This maintains the discrete public dynamics, and introduces both a means to quantify the extent of adhesion to one opinion and a memory effect (individuals do not jump directly from -1 to $+1$, but change their opinions continuously). The model is applied both to the Voter model of interaction, i.e. one agent interacts with one neighbour at each step, and to the Sznajd model, i.e. two neighbouring agents influence the rest of their neighbours. For both cases, the emergence of extremism even in societies of individuals that start with mild opinions at the beginning is shown. Relatively stable domains are formed within the population, which exhibit small changes after they are established. Disagreement dynamics are introduced in the model in Martins and Kuba (2010), by considering part of the population as contrarians (they always disagree with their peers). This has been shown to reduce agreement in the population, but at the same time to discourage extremist opinions, compared to the original model.

The model was also analysed under the assumption of migration in social networks (Martins 2008), where each individual is allowed to change position, a mechanism shown to reduce the amount of extremism observed, yielding one cluster in the end. Further, in Martins (2009), a third opinion is introduced, either as 'undecided' (if p_i is close to $1/2$) or a real alternative (usage of three probability values, p_i, q_i, r_i, for the three available options). In the first case, a decrease in the amount of mild opinions is observed, but at the same time the level of extremism (the maximum absolute value of p_i) decreases. In the second case, there are two different analyses performed. When the third opinion is considered independent (1), the level of agreement is similar between the three options, with extremists for each. Here, for simplification, a set of assumptions about symmetry between the choices are made. When the third choice is a transition between the initial two (2), a higher number of individuals adhering to the middle option is seen.

An additional analysis (Martins 2012) consisted of making agents also aware of the possible effect they have on the others, and discusses also the relation to other models in the literature. The concept of 'trust' was introduced also Martins (2013), with agents holding an array with the probabilities that the others are trustworthy. These probabilities evolve in time, and the system was shown to reach either agreement (for higher trust) or polarization. This study also showed that agreement is reached faster than polarization. In Deng et al. (2013), the observation range of agents is increased and so called 'clustered early adopters' are introduced (i.e. neighbours holding the same opinion), however are shown to not have a better chance of imposing their opinion compared to randomly spread adopters.

The CODA model has been applied to the study of the adoption of theories in the scientific world (Martins 2014), where agents could support a theory or another with certain probabilities. Also, 'experimentalists' were defined as agents who not interact only with peers, but can also receive information from 'Nature' (an interpretation of an external information source). A fraction τ of the scientific world is made of experimentalists, and the model indicates that if τ is small it is difficult to convince the scientific world of the validity of a theory even if indicated by experiments, unless retirement is also integrated into the model (older agents are replaced with new ones with moderate opinions). Also, the small-world case was analysed and shown to increase the adoption of the correct theory.

17.2.2 Multi-Dimensional Models

17.2.2.1 Discrete Opinions

The Axelrod Model The Axelrod model for culture dynamics (Axelrod 1997) has been introduced to model culture formation based on two principles, the preference of individuals to interact with similar peers (homophily) and the increase in similarity after an interaction appears (also termed social influence). The culture of an individual in a population of N is modeled by F variables $(\sigma_1, \ldots, \sigma_F)$. Each of these can assume q discrete values, $\sigma_f = 0, 1, \ldots, q-1$. The variables are called cultural *features* and q is the number of the possible *traits* per feature. They model the different "beliefs, attitudes and behaviour" of individuals. Two individuals i and j interact based on their position (interact with neighbours) and their corresponding overlap:

$$o_{ij} = \frac{1}{F} \sum_{f=1}^{F} \delta_{\sigma_f(i), \sigma_f(j)}, \tag{17.16}$$

where $\delta_{i,j}$ is Kronecker's delta. The value of o_{ij} is the probability to interact: one of the features with different traits $(\sigma_f(i) \neq \sigma_f(j))$ is selected and $\sigma_f(j) = \sigma_f(i)$ is set. Otherwise nothing happens. So, interaction brings individuals closer together and is more likely for similar individuals, becoming impossible for individuals sharing no trait.

From a finite random initial population, the system evolves to one of many possible absorbing states. These can be of two types: either an ordered state, where all individuals share the same traits (q^F possible states) or a frozen state where multiple cultural regions coexist. The number of possible traits q in the initial

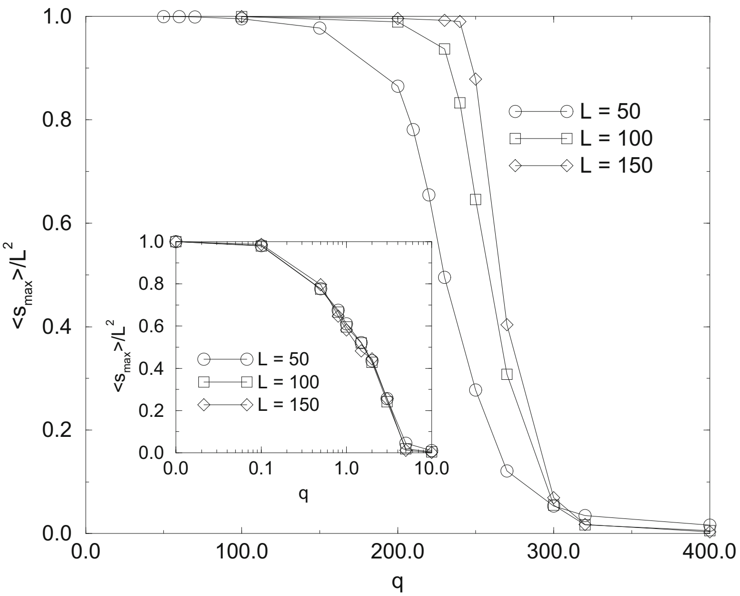

Fig. 17.5 Axelrod model. Behaviour of the order parameter $\langle S_{max} \rangle / L^2$ vs. q for three different system sizes and $F = 10$. In the inset the same quantity is reported for $F = 2$. From Castellano et al. (2000)

population determines which of the two types of final states is obtained (Castellano et al. 2000). When q is small, individuals share many traits so interaction and thus increasing similarity is facilitated, leading to consensus. For larger q, consensus is not reached because of a limited number of shared initial traits, which results in limited interaction and formation of cultural domains unable to grow. On regular lattices, the phase transition between the two types of states appears at a critical value q_c, depending on F (Fig. 17.5).

This model has been widely analysed after its introduction, and here we present the more recent investigations. Although most studies were numerical, some analytical proofs were provided in Lanchier (2010), where it is shown that for $F = q = 2$ the majority of the population forms one cluster, while a partial proof for the fact that, if $q > F$, the population remains fragmented, is provided. Also, Lanchier and Scarlatos (2013) show that for the unidimensional case, the system fixates when $F \leq cq$ where $e^{-c} = c$. Here, fixation means that the state of each individual is updated a finite number of times, until the system freezes. A similar model, designed as a generalization of the models employing homophily and influence, was introduced in Kempe et al. (2013). Here it is shown analytically that in a system where all individuals can interact, all initial conditions lead to convergence to a stable state (invariant). In Barbosa and Fontanari (2009), the dependence of the number of cultural clusters on the lattice area ($A = L^2$, where L is the dimension of the lattice) was analysed. They show that when $F \geq 3$ and

$q < q_c$, a strange non-monotonic relation between the number of clusters and A exists. Specifically, the number of coexisting clusters decreases beyond a certain threshold of the area, in contrast with well known results for species-area relaxation, where the number of species increases with A. Outside these parameter values, however, the expected culture-area relaxation is observed. This is described by a curve that is steep at first (i.e. the number of clusters increases linearly with A) and then flattens when the maximum number of possible clusters (q^F) is reached.

A recent extension (Pace and Prado 2014) introduced a slight modification in the updating rule, by choosing always an interacting pair of agents instead of random neighbours. This was shown to introduce surface tension in the model, resulting in metastable states for certain parameter values. Figure 17.6 compares the dynamics of the original and surface tension Axelrod models.

Studies of the effect of cultural drift (external noise, i.e. some times agents choose to change one opinion randomly) Klemm et al. (2003) showed that even a very small noise rate leads the system to agreement, while large noise favors fragmentation of cultures. Similar results were found in De Sanctis and Galla (2009), where an additional analysis of interaction noise (i.e. the probability to interact is modified by a small δ) showed small effects on the phase transition, but a reduction of relaxation times.

Disagreement dynamics have also been introduced (Radillo-Díaz et al. 2009), using a hard threshold for the overlap, under which individuals disagree. Disagreement causes individuals to change a common opinion on an issue, i.e. decrease their overlap. Two different versions of this model have been developed, one where all individuals can agree or disagree, and one where a fraction of individuals always agrees. In both cases, disagreement dynamics are shown to favor culture fragmentation.

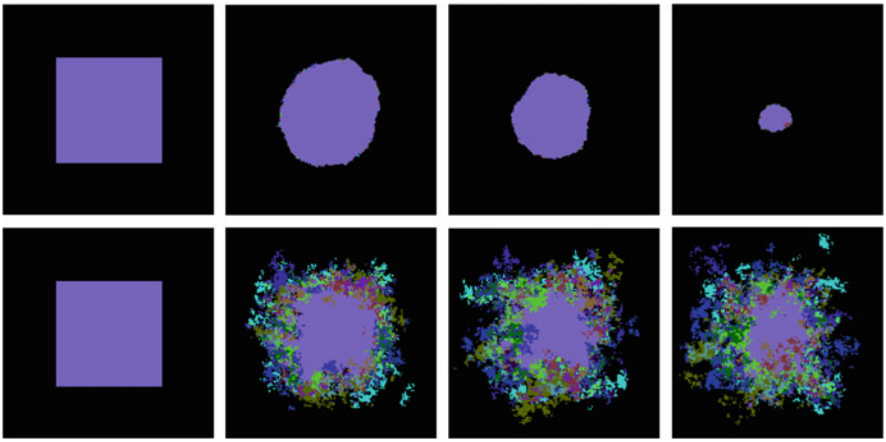

Fig. 17.6 Example of population evolution for the Axelrod model (*bottom row*) and the version with surface tension (*top row*). From Pace and Prado (2014)

In Singh et al. (2012), committed individuals were introduced. These are individuals that do not change the opinion on one of the F issues. They are introduced as a fraction p of the whole population. Also, the social network evolves. The original Axelrod dynamics are changed. At each time step, an individual i is selected, and one of their neighbours j. If $o_{ij} < \phi$, a newly defined model parameter, Axelrod dynamics are followed, otherwise, the link between node i and j is removed and a random node is linked to i. The change in consensus time due to the introduction of committed individuals is analysed. For $p = 0$, consensus time grows exponentially with N, showing that rewiring impedes consensus in the population. When $p > 0$, consensus time is decreased. For $p < p_c \sim 0.1$, the exponential dependence is conserved, while for $p > p_c$, this becomes logarithmic in N. This shows that the introduction of committed individuals favors consensus in the population.

A study of the model on scale-free networks was presented in Guerra et al. (2010). This analyses individuals both at "microscopic"—individual feature value - and "macroscopic" level—entire vector of features. The aim is to study how cluster composition changes when moving between the two levels. They show that even when many individual features are common in the population, the global culture is still fragmented.

In Banisch and Araújo (2010), an application of the model to election data is presented, using a model version with only two possible discrete opinion values. Good similarity to election data is exhibited by the model during the transient stage of the dynamics, i.e. before opinions stabilize, when the vote distribution for each party follows the same scaling observed in real data.

17.2.2.2 Continuous Opinions

'Cultures' in the sense of the Axelrod model can be represented with continuous variables by extending continuous models like the HK to vectorial opinions (with K components). Hence each position in the vector of opinions refers to a different issue. Bounded confidence dynamics lead to formation of clusters similarly to the one dimensional opinions, as shown in Fortunato et al. (2005) for two dimensions.

A different approach is presented in Lorenz (2006). Here, the different vector elements are not independent, like in the previous models, but they are constrained to sum to unity. In this way, the different values could represent probabilities of choosing an opinion out of multiple possibilities on the same issue, or could model a resource allocation problem. The model applies bounded confidence, by using the Euclidean distance between two individuals (d_{ij}). Two model versions are analysed, following Deffuant-Weisbuch and Hegselmann-Krause dynamics. For the former, individuals interact if $d_{ij} < \varepsilon$, when one of the peers takes the opinion given by the average between itself and the neighbour. Updating rules similar to the original Hegselmann-Krause model are also defined. The model is shown to converge to one or more clusters depending on ε and K. When the number of options K increases, the model is shown to obtain better agreement (large maximal component), but at the same time a larger number of small separate clusters. Also, when ε increases above a threshold, the population converges to one opinion. This threshold decreases with K. A comparison of this approach to that of considering the K elements independent is provided in Lorenz (2008). In the independent case, agreement is not facilitated by an increase in K.

In Deffuant et al. (2013), continuous opinions are applied to model individuals' opinion about others and themselves, i.e. each individual holds a set of N opinions. An analysis of vanity and opinion propagation is performed, under the idea that opinions from highly valued individuals propagate more easily. For large vanity, individuals cluster in groups where they have a high opinion of themselves and other group members, and low opinions of peers external to their group. If vanity is lower, then some individuals gain high reputation, while most of the population have a low one. Situations with one or two agents dominating the others are exposed.

A different approach using continuous opinions and affinities between individuals is presented in Carletti et al. (2011). Each individual holds a real opinion $x_i \in [0, 1]$ plus a set of affinities to all other agents, i.e. a real vector $\alpha_i \in [0, 1]^{N-1}$. These are updated simultaneously during agent interaction. The bounded confidence concept from the Deffuant model is maintained, but the definition is changed to accommodate for affinity values between individuals. Specifically, even if the opinion of two agents are not close enough, if their affinity is high, then they can still interact. Affinities, on the other hand, decrease if individuals hold diverging opinion and increase when their positions are close. The update rules are thus:

$$x_i^{t+1} = x_i^t - \frac{1}{2}(x_i^t - x_j^t)\Gamma_1(\alpha_{ij}^t) \tag{17.17}$$

$$\alpha_{ij}^{t+1} = \alpha_{ij}^t + \alpha_{ij}^t(1 - \alpha_{ij}^t)\Gamma_2(x_i^t - x_j^t) \tag{17.18}$$

where $\Gamma_1(\alpha) = \frac{1}{2}[\tan h(\beta_1(\alpha - \alpha_c)) + 1]$ and $\Gamma_2(x) = -\tan h(\beta_2(|x| - d))$ are two activating functions that tend to step function when β_1 and β_2 are large enough. Parameters d and α_c are the confidence thresholds, i.e. affinity values increase if opinions are closer than d, while individuals interact if their affinity is larger than α_c. The model starts with random opinions and affinities, and is allowed to relax to a stable state. Affinities are then interpreted in terms of a weighted social network, with α_{ij} the weight of the link between agents i and j. The authors show that the network obtained display small-world properties and weak ties.

17.2.3 Modelling Norms

Modelling norm compliance is closely related to opinion dynamics. Norms are rules enforced within society and sometimes also by law. A person can have an opinion about a norm, in the sense discussed until now, however norm compliance relates more to final behaviour, compared to opinions only. Opinions are in general indicative of behaviour, however there are cases when actions are taken in spite of contrary opinions, due to social or external pressure. Hence there are several factors to be taken into account when trying to model norm emergence, respect and violations. These start from internal predispositions and opinions, and extend to imitation of peers and, unlike pure opinion dynamics, to responses to some form of punishment.

Several agent-based approaches for building models for norm emergence and violation have appeared, many of which have a base in Game Theory. Cooperation is viewed as compliance to a norm, and defecting means norm violation. Agents hold a state that defines their strategy or probability to choose one, and change this in an attempt to maximize an utility function. This function includes different costs, punishments, rewards, etc. States are also changed based on the behaviour adopted by peers. The game theoretic literature contains many such approaches, while other hybrid agent based models have appeared recently. We give here a few recent examples of such models, to give a general idea of various approaches following these lines.

A recent example agent-based model of norms (Fent et al. 2007) shows norm evolution and coexistence in a population. Individual behaviour is represented by a continuous variable (representing the degree of adherence to a norm or another) and evolves based on in- and out-group interactions. Agents tend to be more similar to their in-group and more distant from their out-group, while being also reluctant to change behaviour. Specifically, dynamics are determined by the objective of maximizing a utility function, which includes the difference between agents and out-group, the similarity between them and in-group, and the closeness between their own behaviour at time t and $t+1$ (punishment for lack of persistence). Simulation results show that when the out-group is small, the population reaches consensus to a mild behaviour, for a medium out-group several clusters form, while a large out-group results in clusters where the two extreme behaviours are acquired. This approach is very similar to opinion dynamics models, but adds the existence of punishment and the usage of the utility function.

In Helbing et al. (2010), a population of K individuals is divided into four types (four possible behaviours): cooperators, defectors, moralists (cooperators that punish with a cost) and immoralists (defectors that punish). Agents change their behaviour in time, based on spatial interaction with their neighbours, i.e. they have a larger probability p to imitate their neighbour if this has a payoff P_n larger that their own (P_s)—so called 'replicator' dynamics :

$$p = \frac{1}{1 + \exp[(P_n - P_s)/K} \tag{17.19}$$

The spatial effect gives an advantage to moralists, which prevail in the population, so the social norm eventually wins, with the moralists shown to profit from the presence of immoralists and defectors.

Ignorance about norm compliance levels is discussed in Groeber and Rauhut (2010). The question is whether hidden norm violations can enhance or not norm compliance in general. The model includes a population of agents and an inspector agency. Agents can choose to violate or adhere to a norm, and how much effort they put in concealing a violation, while the inspector agency decides how much to invest in inspections. The chosen behaviour is derived from the publicly known number of violations plus a belief of how many undetected violations there are (a suspicion level). Various means of defining the choice and other parameters of the model are explored. The main results show that when norms are enforced by peers, ignorance reduces norm violations. However if enforcement is performed by a third party inspector, who receives awards depending on the violations discovered and punished, then ignorance actually increases the number of violations in the population. The opposite effect is explained by the competition between inspectors and agents.

Recently, a study of collective behaviour (Centola 2013) looks at critical mass self reinforcing dynamics and how these affect stability. Willingness to participate in collective behaviour is similar to complying with a certain norm, and defines a certain agent behaviour. Here, critical mass systems are employed, where the incentive to participate increases with the number of participants (self-reinforcement). Free-riders are however still allowed, generating a so called ‘weak’ self-reinforcement: after a certain participation level is reached, some agents might decide not to participate, since the collective behaviour is already established (incentives peak out before the collective behaviour reaches the entire population). Although in general full participation is aimed for, the authors show, using a simple threshold model, that weak self-reinforcement has the advantage of greater stability (resilience to perturbations), generating larger participation in the long run.

A similar approach to look at norms in a public-goods setup (Tessone et al. 2013) showed the appearance of so called diversity-induced resonance in an agent based model. The model considers ‘conditional cooperation’, a concept similar to self reinforcing dynamics, where the willingness of a user to follow a norm increases with the mass of followers. Sanctions are introduced to represent social pressure, which depend on the number of agents violating the norm and an individual ‘sensitivity’ to this pressure. This creates diversity in the population. Additionally, the norm changes in time, by changing the effect of the social pressure. A utility function is defined using all these components plus the cost of cooperating and the gain from the public goods. Agents need to maximize their gain, using evolutionary dynamics. Two approaches are analysed, the replicator dynamics with noise and logit dynamics (compare the payoff for the two possible behaviours). The results show that indeed, norm compliance levels are maximized for a certain level of diversity. Similarly, an optimal range of noise levels exists, to maximise norm compliance.

In Schweitzer et al. (2013), cooperation is analysed in an interactive population in a prisoner dilemma setting. A heterogeneous model is employed, including aspects of the non-linear voter model (Sect. 17.2.1.1). The strategy chosen by an agent at each time step depends not only on the previous payoff, but also on social interactions (social herding): agents would also take into account the fraction of cooperators in their neighbourhoods. The social effect was shown to facilitate the adoption of cooperation as a strategy, i.e. norm compliance.

A different agent based model for norm compliance has been introduced in Pietrosanto (2013) and Di Carlo (2015). Here agents hold a state variable determining their behaviour, i.e. a probability to respect or not a norm $\sigma_i(t)$, that evolves in time. Each agent has a natural predisposition to respect a norm (ρ_i), and this is also the initial state. However, at each time step, agents interact in groups, randomly selected from all agents, and change their state depending on several factors. All agents tend to relax to their natural predisposition, respond to social forces (getting closer to the states of the others in the group) and can be punished (with probability p) in case they do not respect the norm, which makes them increase their respective $\sigma_i(t)$. In this model, no measure of payoff is used, as opposed to previous methods. Punishment is shown to increase the level of adherence to the norm, effect whose extent depends on the time scale at which the state relaxes to the natural predisposition. A 'pack effect' is also introduced, where agents feel the punishment less if their group behaves the same as them. This is shown to slightly decrease the levels of norm adherence.

Norms in social (peer) production systems have been analysed in a general framework of calibration for social models (Ciampaglia 2013). The emergence of such norms has been shown using a model calibrated with data from Wikipedia online communities. This links the process of norm emergence to population dynamics. Beliefs are modeled similarly to the Deffuant model, using continuous variables and bounded confidence. However, here we find two types of agents: users and pages. Users interact only with pages using Deffuant rules, i.e. by simulating the editing process, and in this way get an idea of the beliefs of other users. This interaction changes the state of the page and of the user. A second type of interaction is included, to model sanctions: only pages change their state, meaning that vandalism is removed with no effect on the user making the correction. The user population changes in time, with new users joining and old users retiring. Similarly, pages are created at a certain rate, and the selection of pages by users is performed based on their popularity. Indirect inference was shown to be suitable for fitting model parameters with the experimental data from the online community.

17.3 Effect of External Information on Opinion Dynamics

The models we reviewed so far apply to situations in which consensus spreads or tries to spread among populations according to peer mutual interactions. There is no reservoir, to use a term coined in physics, with which or against which the population interacts. This limitation can be justified in few special cases, as for instance the spreading of dialects or regional behavioural habits, where the external pressure pushed on individuals comes from the interactions among the individuals themselves. On the other hand, we are nowadays bombarded by a huge amount of external information, "external" meaning here that such information comes from other sources than word of mouth. We live in a world where the mass media play a fundamental role. In order to understand whether it is feasible to achieve whatever behavioural changes in the population in response to given stimuli, we must consider models in which there is an external source of information. Some efforts in this direction have been made by the scientific community so far, however approaches are still limited to only a few of the models presented in the previous section. In the following paragraphs, we review the state of the art of opinion dynamics modelling with external sources of information.

17.3.1 One Dimensional Opinion

17.3.1.1 Discrete Opinions

The effect of mass media has been studied for the Sznajd model on a square lattice (Crokidakis 2011), by introduction of an external agent (media, having value e.g. $+1$). If four neighbours agree, then all their other neighbours switch to their opinion. If they do not then the neighbours take the media opinion with probability p. It was shown that the final state (either all spins up or down) depends on both the initial density of up-spins and on the value of p. The larger p, the smaller the initial density of up-spins has to be to ensure full agreement to the media. For $p \gtrsim 0.18$, the population always converges to the value of the information. In Sznajd-Weron et al. (2008), an extension of Sznajd to three opinion states was applied to the mobile telecommunication market in Poland. The effect of media is introduced, i.e. an individual accepts the plaquette opinion with probability p, or the influence from media with probability $1-p$. Media is represented as a set of probabilities to choose one of the options. The authors found that for low advertising, small companies are taken over by larger ones, as it happens in reality.

External information with accuracy was studied for a binary opinion model in González-Avella et al. (2011). Here, the two opinion options are not equivalent and external information could take, at different time steps, one value with probability $p > 0.5$ (the true or the most beneficial opinion) or the other value with probability $1-p$. At each time step a random agent was chosen to interact with this information. If the opinion of the agent was different, then it would be updated only if a fraction of the neighbours larger than a threshold τ held the same opinion as that of the external information. The system was shown to reach consensus to information only for intermediate values of τ, with mixed populations with fluctuations obtained for small τ, while for large τ the population froze in the initial state.

Non equivalent binary opinions were also investigated in Laguna et al. (2013), where agents hold either opinion 1 or 2, the second being the right one. Individuals update their opinions based on small group interactions where a poll decides whether to change or not. In this poll, the higher value of one opinion counts, and a weight is used for the self opinion (conviction). With probability P, agents can, instead of interacting with peers, interact with a so called ‘monitor’ which forces them to adopt opinion 2. This is one way of introducing external effects, where the persuasion of the external field is infinite. A different way is using a set of static individuals (educated group) that follow the same interacting rules as normal agents when spreading their opinion, but do not change their state. The two options are shown to increase adoption of the right option, however the educated group was less efficient than monitors.

17.3.1.2 Continuous Opinions

Effects of external information on the dynamics of the Deffuant model have been also investigated (Carletti et al. 2006). All individuals are exposed to an external source of information O, which promotes a specific opinion. Every T generations, the entire population interacts with the information. These interactions follow the same rules as with other individuals: the opinion is updated only if the bounded confidence condition is met (see Eq. (17.6) for details). Experiments were performed with $\mu = 0.5$. Dynamics were shown to depend on the value of the information, on T and on the parameter d from the original model. If the confidence is large enough so that the information can reach all individuals, the population converges to this. On the other hand, if confidence is extremely small, it is shown that full agreement with the information can be never reached. If neither of this applies, two types of dynamics are observed:

(1) In the case of extreme information (close to 0 or 1) and low confidence, T has to be in a fixed interval for the complete agreement to information to appear. Outside this interval, some individuals move away from the information forming an additional cluster. This shows that for extreme information to be efficient in a close-minded population, individuals need to be exposed to information often enough, but also need to interact to each other.
(2) In case of mild information or large confidence, complete agreement is found only when T is larger than a threshold. This shows that individuals that do not access the information directly (because the confidence threshold is not met) can be influenced only if a large number of peer interactions are allowed before re-exposure to information. When the population does not converge to the information, still, large fractions of individuals form a cluster around the information value (minimum value over 0.5).

Another approach to analyzing the effects of mass media in an extension of the Deffuant model is Gargiulo et al. (2008), where, each generation, individuals interact with an external information x_I modulated by a parameter ε, the information strength:

$$x_i = x_i + \mu\varepsilon d_i(x_I - x_i), \tag{17.20}$$

where d_i is defined as in Eq. (17.7). For mild information (low ε), individual opinions move towards the value of x_I, however for strong information, an increasing number of antagonistic clusters emerge. This shows that aggressive media campaigns are risky and might result in the population not acquiring the information.

A different model similar to Deffuant's considers both disagreement and effects of mass media (external information) (Vaz Martins et al. 2010). Here, disagreement is included as an attribute $w_{ij} \in \{-1, +1\}$ of the link between two individuals (some couples always agree, others always disagree), and opinions take values in interval $[0, 1]$. The interaction causes a change in the opinion value based on the type of link:

$$x_i = x_i + \mu w_{ij}(x_j - x_i) \tag{17.21}$$

Additionally, an external information source is considered, applied to all individuals after a specific number of updates. The introduction of repulsive links was shown to favor consensus with the external information.

In Hegselmann and Krause (2006), truth seekers are introduced into the Hegselmann-Krause model, i.e. individuals that take into account the value of the truth T. This can be interpreted as individuals who interact with experts, and is similar to the interaction to an external source of information. The opinion of an individual, upon interaction to a peer, changes as

$$x_i(t+1) = \alpha_i T + (1 - \alpha_i) f_i(x(t)) \tag{17.22}$$

where $f_i(x(t))$ is the right term in Eq. (17.9), while α represents the disposition of individuals to seek the truth (which can be seen as the strength of the information). It is important to notice that the effect of the truth is not based on bounded confidence, i.e. it affects individuals with $\alpha \neq 0$ regardless of their opinions. Results show that even for small α (0.1) for all individuals, or if at least for half of the population $\alpha \neq 0$, the population converges to the truth, provided the truth is not extreme. If the truth is extreme (close to ± 1), and not all agents have $\alpha \neq 0$, some individuals remain far from truth. Large values of α may result in more individuals with $\alpha = 0$ to stay away from truth, which means that too strong information may have a disadvantageous effect. A further analysis of the model with truth seekers is presented in Kurz (2011), where it is proven analytically that all truth seekers (individuals with $\alpha \neq 0$) converge to the truth, even if there are agents that do not seek the truth.

Multiple interacting mass-media sources for the Deffuant model are analysed in Quattrociocchi et al. (2014). Here, agents are placed on a scale-free network and media sources on a complete network. Agents interact with others and the media using Deffuant dynamics. A media source interacts with the others by choosing, among its neighbours, the most successful one and getting closer to it in the Deffuant sense. Competition between media sources is also introduced by allowing disagreement between competing media sources. The system is shown to display stable clusters of different opinions. Additionally, media competition appears to favor fragmentation in the population.

17.3.2 Multi-Dimensional Opinion

17.3.2.1 Discrete Opinions

The effect of mass media or propaganda for the Axelrod model has been widely studied, by introducing an external agent (information source, field) that can interact with the individuals in the population. One approach is to introduce a parameter p that defines the probability that, at each time step, an agent interacts with the information instead of a peer (González-Avella et al. 2010, 2006; Peres and Fontanari 2010, 2011). In this case, it was shown that, surprisingly, a large probability to interact with the information actually increases fragmentation instead of favoring agreement. However, this could be explained by the fact that increasing the frequency of interaction to the external agent decreases the possibility of agents to interact between themselves. Hence there is an interdependence between peer and field interactions. This, coupled with the fact that, at the beginning, some individuals cannot interact with the information (low overlap), causes an isolation of these and creation of additional clusters.

In the above cited approaches, the external information was independent of the state of the population and never changed. Several other ways of defining external information were also analysed in González-Avella et al. (2007, 2012, 2006), where so called global and local endogenous fields were considered, on a two dimensional lattice. These were computed as the statistical mode of opinions either over the entire population (global) or over the neighbourhood of each agent (local), and accounted for endogenous cultural influences. These fields were also shown to facilitate segregation in the population, for large p, while for low p, cohesion and alignment to the information was observed. Quantitative differences between the types information were uncovered, with local information sources promoting uniformity in the population. Furthermore, an analysis of two separate populations, where each is influenced by a the global field of the other, has shown complex behaviour (González-Avella et al. 2012), where sometimes one population did align to the information from the others, but also could completely reject it or form a large rejecting minority.

Several methods trying to overcome the interdependency between peer and field interactions, in the quest for induced agreement, have also appeared. For example, Rodríguez et al. (2009) add a set of "effective features" to the individuals, i.e. additional values in the state vector, that are considered to be always equal to the information (mimicking in this way the way media is designed to target a social group). This causes the overlap with the information to be always non-zero, and leads to better agreement to it. Similarly, in Mazzitello et al. (2007), a different definition of overlap to the mass media was used, again non-null for all individuals. A different approach can be seen in Rodríguez and Moreno (2010). Here, the so called "social influence" is used, where individuals are affected by all neighbours (including the mass media, with a certain probability defined by its strength), using a procedure similar to voting. Again, this method increases the number of agents adhering to the external information with the increase in the media strength. Several other model extensions have been analysed, trying to combine the effect of media with noise and social network structure (Candia and Mazzitello 2008; Gandica et al. 2011; Mazzitello et al. 2007; Rodríguez and Moreno 2010).

17.3.2.2 Continuous Opinions

In Quattrociocchi et al. (2011), a Deffuant-like model in two dimensions, with two conflicting opinions (x_i^1, x_i^2), was studied under the effect of external influence from media and experts, on a scale-free social network. The model was applied to opinions on welfare and security. Results showed that when the media message is false, peer interaction can help the population escape the message, only if the media does not reach more than 60 % of the individuals.

A different approach to modelling continuous vectorial opinions has been introduced for a complete graph in Sîrbu et al. (2013) and later for different topologies (Cucchi 2015), including disagreement and external information. Here, opinions are represented by an element in the simplex in $K-1$ dimensions, $\mathbf{x} = [p_1, p_2, \ldots, p_K]$, similar to Lorenz (2006). This can be interpreted either as an opinion on a resource allocation problem or as the probability to choose between K discrete options. The model includes complex interactions, based on a similarity measure defined as the cosine overlap ($o^{ij} = \frac{\sum_{k=1}^{K} p_k^i p_k^j}{\sqrt{\sum_{k=1}^{K} (p_k^i)^2 \sum_{k=1}^{K} (p_k^j)^2}}$). This defined the probability that two individuals will follow agreement (opinions become more similar) or disagreement (opinions become more dissimilar) dynamics. External information (mass-media) is included as a static individual that all agents can interact with, after a peer interaction, with probability p_I. The system was shown to form one or more clusters depending on p_I, initial condition and type of information. Extreme mass-media messages and large exposure to external information proved to have a reduced success in the population, while mild messages and low exposure were more easily adopted by a large number of individuals. Full agreement with the information was obtained either for a very mild message or for a very low exposure of a non-extreme message to a compact initial configuration. The model was further developed in Sîrbu et al. (2013), where multiple media sources were analysed and shown to lead to more realistic behaviour, i.e., stable non-polarised clusters or full agreement for external information which is not extremely mild.

17.4 Final Remarks

The macroscopic properties of matter, where the forces between atoms and molecules are in principle known, can be reproduced by numerical simulations with relative success. On the other end, the emergent collective behaviours of our societies are not easily reproduced by numerical simulations mainly due to the fact that human individuals are already the result of complex physiological and psychological interactions so that the social atom itself has been yet hardly understood. The result of this uncertainty is the proliferation of modelling schemes that try to catch particular aspects of single humans and try to examine what kind of common behaviour such selected aspects might trigger or be related to. While opinions and languages are the result of a social consensus, beliefs and awareness are somewhat more subtle since they require a sort of continuous feedback from the environment. After an individual realizes that a small change of his/her own behaviour may lead to a better social condition, an awareness is acquired and a further phase has to follow to yield real tangible societal advantages. The small cost in changing behaviour, e.g. starting trash recycling to cite one, must be sustained by a sufficiently high number of other individuals for the global advantages to be evident. That is why modelling schemes try to exploit the conditions that lead to consensus similar to what in physics happens in phase transitions, so that an hint can be obtained on how to propel virtuous behaviours and reach the critical number of persons necessary to self-sustain the change.

With the aim to clarify the current literature on the topic of opinion dynamics, we presented an overview of recent methods for social modelling, with emphasis on less explored ingredients, e.g., disagreement between individuals and the effect of external information, which is thought to model the interaction of individuals with mass-media. According to how individual opinions are represented, models vary from discrete one dimensional to continuous multi-dimensional, with several types of interactions introduced. Although under different assumptions, many of these models have led to similar results, which agree also with some observed behaviours found in social systems.

Although lots of original models of opinion dynamics consider mostly attractive behaviour, i.e. two individuals sharing common interests or opinions tend to come closer to each other, the necessity to build approaches that have applicability to real settings has triggered introduction of different other types of interactions. Hence disagreement (contrarians), independence and zealots have been introduced in many of the models. These elements were shown to facilitate the coexistence of multiple opinions in all models, regardless of type. At the same time, the introduction of more realistic interaction rules slowed down convergence to a stable state.

Noise was also analysed for most of the models discussed here, in the form of sudden shifts of opinion, which in reality can happen often. Low noise levels facilitate consensus both for continuous (e.g. Deffuant) and discrete (e.g. Axelrod) models. High noise, on the other hand, leads to instability of the system, either in the form of disorder or fluctuating clusters.

Different social network topologies do not have a large effect on the consensus time and qualitative structure of the final population for most models, however quantitative structure of clusters may change. When networks evolve together with opinions, consensus or cluster states can still appear. On the other hand, non symmetrical interaction between individuals, i.e. link directionality, was shown to induce fragmentation in several cases.

The effect of external information is very important in studying real social systems, however the extent of models including this aspect is reduced. Previous analyses have concentrated mostly on the Axelrod and Deffuant models. For other discrete models, an external field generally causes trivial consensus to the field, while a few scattered efforts have been made to analyse multidimensional continuous systems with alternative dynamics. In general, external information was shown to cause fragmentation when it is too extreme or too strong, for both discrete and continuous opinions. Mild information, analysed in the context of continuous opinions (in discrete models information is always extreme), was shown to induce cohesion in the population. This matches findings from chapter by K. Akerlof of this volume, where governmental pressure related to environmental issues was shown to have opposite effects if not suitably expressed.

Most analyses concentrated on one static information source. However in reality information comes from multiple sources and is continuously changing. This change is many times also affected by the feedback from the population. These issues have been only slightly touched upon by the literature, and difficulties still remain in devising a framework where media and agents interact bidirectionally in a manner similar to society.

The traces that society leaves of interactions and other effects are nowadays more and more at reach with the new communication technologies. Behaviour data can be extracted from various types of sensors, as we have seen in chapters by V. Kostakos et al., by D. Ferreira, V. Kostakos, and I. Schweizer and by Gautama et al. of this volume, but may also come from the new discipline of human computation and gaming, for which an overview was presented in this book in the chapter by V.D.P. Servedio et al. These data are enabling many analyses of social systems. However, when it comes to opinion formation, although conclusions from the different models appear to be realistic, application to real data is still very scarce. In general, outputs from discrete models have been compared to patterns seen in the data, such as strategic voter model and election output, majority vote model and debates or financial market crashes, tax evasion with majority vote and Sznajd. However, studies still concentrate on qualitative similarities, with a complete lack of quantitative analyses on real data.

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Chapter 18
Final Considerations

Vittorio Loreto and Francesca Tria

EveryAware was a pioneeristic project and very soon new initiatives have been conceived and are thriving along the same direction.

We think the very important lesson we can take from EveryAware is a very early proof of concept of the powerful feedback loop linking technology and people engagement, with the final goal of enhancing both environmental and civic awareness.

From this perspective, it is important to summarize what we learned and the possible directions ahead to make the EveryAware experience durable and sustainable on a large scale. We identified three main developments that should coexist, in our opinion, in all next initiatives, to support a large scale approach. First of all the ICT infrastructure should be deeply redesigned to become modular, flexible and ready to accommodate progressively new technologies. Second, a strong attention should be paid to a cooperation with a diversity of environmental grass-root communities in different countries (e.g., cyclist communities, NGOs aiming at creating a network of environment-aware communities, nature-preserving NGOs, etc.), that will act themselves as hubs for a variety of other local communities. Finally, it would be important to provide community services and setting up crowdfunding facilities, with the aim of attracting further local communities, in locations not already reached by the project activities. This last point is related to a further crucial goal, that of the self-sustainability of the EveryAware or similar activities, well beyond the naturally short and finite duration of the funding activities giving the initial boost. To this end, possible commercial solutions could be considered with the open source licensing

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scheme adopted so far. This, together with the modularity of the whole platform, will also trigger further advances on the whole infrastructure, allowing users to improve it and to readapt it for specific needs.

More specifically, we can foresee the following points as promising steps to extend the EveryAware experience and make it sustainable on a large-scale, endowing citizens with effective tools to gauge and steer the evolution of our cities and triggering a long-awaited U-turn in the management of our environment.

Developing an open source hardware platform letting citizens to capture, process and send online geo-referenced physical data about air-quality. The platform has to incorporate an interoperable set of sensors and has to be developed with a modular approach, aiming at guaranteeing interoperability between communication standards, as well as low consumption. The board could communicate with a smartphone, possibly with a WIFI connection or a 3G tower, in order to give an immediate feedback to the user and to further exploit, through a specifically devised app, all the potentiality already embedded in the mobile device (such as accelerometers, microphone, etc..), or directly to a central server unit for data storage and processing. The platform has to be thought as intrinsically modular, to also allow different communities to integrate it with possibly different sensors corresponding to their specific requirements. A specific effort should be devoted on the usability of the whole hardware platform, including wearability and horizontal economical accessibility (low cost compatible with reliability). As already in the framework of EveryAware, it will be crucial to put a great deal of attention to a proper calibration and periodic (re)calibration of the sensors, a notoriously non-trivial task for low-cost sensing devices, also considering the natural degradation of sensors and their innovation tracks. Further, the board and the site infrastructure should be released under open licenses, thus allowing users to hack it and possibly make it better, following the ideas of active citizenship, transparency, open data and open source models. The whole approach is based on allowing users and communities joining the project activities, including taking part to the development and bug fixing processes, with the aim of providing an affordable, reliable and scientific tool to witness and testify environmental and living conditions.

Developing an open source software platform to collect subjective data and engage citizens to provide information, related to their perceptions, learning, behaviour and choices. Further, a web platform specifically devised for web-based games/experiments (such as www.xtribe.eu), could be exploited to set up a set of web-based experiments, presented with a playful aspect in order to attract players at most. Such experiments are meant as complementing the information acquired with direct methods of measuring and provide progressively more reliable maps of the cities as perceived by users. Possible game scenarios can cover negative environmental aspects as the detection of polluted spots, uneven roads, broken or unused common facilities, while positive aspects can involve best locations in the city, aggregation points, agreeable areas. Also, simple polls could be used to directly probe citizen opinions. Finally, specific experiments could investigate the mechanisms affecting the behaviour of single agents at a microscopic level and how complex phenomena at meso- and macro-scales may emerge. In particular, measuring behavioral inertia would be key to elucidate the role of the network of acquaintances as well as that of different timescales in the emergence of new opinions or shifts in behaviour. Overall, this platform could provide geo-localized information related to the way citizens perceived their urban environment, as well as possible hyperlocal recommendations. Those annotations could be validated by other users in a self-sustaining mechanism with the potential to provide the community as a whole and policy makers in particular with trusted and capillary information about their city and the way citizens perceive it. Those data could integrate the objective data concerning air-quality and noise pollution.

Fostering the creation of a network of environmentally aware communities. It is important to create platforms that could act as basins of attraction both to coordinate collective actions towards a more sustainable organization of our cities, and a meeting point for different communities, from technically oriented (e.g. Civic Hacking or Maker Movement) to socially oriented (nature-preserving, educational, clean-mobility promoting, etc..) ones, fostering interdisciplinary collaborations. A special attention could be devoted in engaging users and communities to join the activities to take part also in the development processes, in an aim of providing an affordable, scientific tool allowing them to witness and testify climate conditions, and more in general to foster actions towards an environmental monitoring and care. Different methods could be foreseen, from involvement through community hubs directly involved in the project, to attendance to public events (local or with a broader audience), workshops, mass-media communication channels, web based dissemination, social networks, etc. The role of each of these methods in recruiting participants, and their level of engagement, should be carefully analysed, and continuously refined to achieve effective standards for a wide scale participation.

We think the combination of the above mentioned tools could be key to foster and detect the outset of awareness and monitor it in time. The study of the combination of subjective and objective data, accomplished through statistical physics and machine learning tools, has the potential to shed light on which factors affect human perception and how people elaborate their own information to react accordingly. The personal involvement in sampling the environment has the potential of leading to an increased awareness of citizens with respect to their living surrounding. We should aim at understanding under which conditions the emergence of awareness is supported and for this EveryAware already tested a suite of different methods coming from data science, complex systems modelling and web-based experiments, always taking advantage and inspiration of the long experience of social sciences as applied to opinion and cultural dynamics, decision making and behavioural changes.

Erratum to: Participatory Sensing, Opinions and Collective Awareness

Vittorio Loreto, Muki Haklay, Andreas Hotho, Vito D.P. Servedio, Gerd Stumme, Jan Theunis, and Francesca Tria

Erratum to:
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The publisher regrets to inform that the initial for one of the book editors was incorrect. The correct name is Vito D.P. Servedio (wrong: Vito C.P. Servedio).

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Erratum to: Observing Human Activity Through Sensing

Sidharta Gautama, Martin Atzmueller, Vassilis Kostakos, Dominique Gillis, and Simo Hosio

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The publisher regrets that the spelling of the author Vasillis Kostakos was incorrect. The name should read as Vassilis Kostakos.

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