# Introduction

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The project that resulted in this book originates in an encounter of three of the authors (David Lane, Sander van der Leeuw and Geoffrey West) in the summer of 2001 at the Santa Fe Institute around two main themes: (1) a different way of looking at the invention and innovation of artefacts, and (2) the possible impact of innovation on urban dynamics. One of us was a physicist (West), one a statistician (Lane) and one an archaeologist (van der Leeuw). Almost immediately, we asked Denise Pumain (an urban geographer) to join us in this adventure.

Fortunately for us, our meeting coincided with an initiative of the head of the newly formed unit for a project officer of the Future and Emerging Technologies Program of the European Union's Directorate for Information Science and Technology, Dr. Ralph Dum, to stimulate a wide spectrum of research into the potential uses of Complex Systems approaches. Hence, we brought four teams together, at three European universities: the University of Modena and Reggio Emilia (Lane), the University of Paris 1 (Panthéon-Sorbonne) (Pumain and van der Leeuw), and Imperial College, London (West).

Ralph encouraged us to apply, and after the usual vetting procedure our proposal for a project that considered the Information Society as a Complex System (ISCOM) was accepted and funded. We began work in July 2002, and the project lasted for four years, until the end of June 2006. Those years turned out to be a very exciting intellectual adventure for all of us, as well as the members of our teams and the colleagues whom we invited to our workshops in London, Santa Fe, Venice, Modena, and Paris. Some of the results lie in front of you. But we do not think that we are exaggerating if we say that the collaboration influenced the thinking of all of us to such a point that other results will follow in due time, whether under our name or under that of the many other members of the team (see the list that follows this introduction).

Two conclusions stand out from the project. Firstly that innovation and invention have, in a sense, been among the stepchildren of modern research, whether in the

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social sciences or in the humanities, and secondly that the role of innovation in urban dynamics is much more important than is generally acknowledged.

We live in a world that is driven by invention and innovation, but that has not always been so. In the XVIIth century, innovation was a ‘dirty word’. The world order was deemed to be immutable; people behaved as their ancestors had done (or at least they believed they did, and they often strived hard to meet that ideal) (Girard 1990).

Little by little, though, over the last three centuries, ‘history’ and ‘tradition’ ceded place to ‘nature’ as the concept invoked to explain the world order. We still speak in many instances of ‘it is natural’ when we wish to express the fact that we think that a kind of behavior is in harmony with the world order. In the process, in the first part of the XIXth century, History has become a discipline, rather than the omnipresent way to explain what happened or what happens.

Simultaneously, we observe a growing *emphasis on the new rather than the old* – particularly during, and as a result of, the Enlightenment and the Industrial Revolution (Girard, 1990). As science and technology gained in importance, the conceptual and instrumental toolkit of the (western) world grew exponentially, and in doing so enabled humanity to identify and tackle more and more challenges. As a result, the number of inventions and innovations around us is increasing dramatically. This is clearly visible if one looks at the number of inventions that are patented in the industrial countries.

After the industrial and nuclear revolutions, we are now witnessing the silicon, information technology and communications revolutions, and the nanotechnology, biotechnology, and cognitive revolutions are on the horizon, each of which is opening another whole new domain of knowledge, know-how and innovation. For the moment at least, there does not seem an end in sight to this acceleration of change in our world.

In that context it is in our opinion surprising that the scientific community has generated so little understanding of the process of invention and innovation itself. Generally, the world reacts *a posteriori* to innovations once they have been introduced. Could we not attempt to shift our stance from a re-active to a pro-active one, and come to understand and guide the process of invention and innovation itself? That would put us in control rather than dealing with things after they have gotten out of hand, and it would potentially allow us to accelerate the innovative process in those domains in which that is most needed, and maybe slow it in others

What has thus far held back our understanding of the process of invention and innovation? Our tentative working hypothesis is that this lack of understanding is directly related to the fact that the majority of the scientific community has looked at invention and innovation using a positivist, scientific perspective. In essence, invention and innovation have mainly been studied ‘a posteriori’. From such a perspective, creation cannot be described or understood. Hence, we have left ‘invention’ completely to one side in innovation studies, relegating it to the domain of ‘personal creativity’, and we have focused uniquely on innovation, i.e. on the ways in which an invention is adopted and spreads throughout a population.

The first towns in the world were founded about six or seven thousand years ago. After a slow start, urbanization is now everywhere around us. Currently, about 50% of the world population lives in towns, and this number is growing so rapidly, that the 80% threshold may be reached within twenty to forty years. In effect, urbanization seems to be an unstoppable 'explosion' that is only equalled by the explosion in inventions we have seen over the last century or so. Hence, the idea that there might be a relationship between the 'innovation explosion' we have just referred to and the 'urban explosion' seems worth looking into.

Our team has convincingly demonstrated that innovation (as represented by the number of people involved in research, the number of research organizations, the number of patents submitted, etc.) scales super-linearly with the size of urban agglomerations, while energy scales sub-linearly and services linearly (cf. Bettencourt, Lobo, & Strumsky, 2007; Strumsky, Lobo, & Fleming, 2005, Bettencourt et al., 2006; Pumain et al., 2006 and Chapters 7 and 8 in this book). This seems to point to the fact that, whereas economies of scale in energy use are an important phenomenon in urbanization, managing information–generating new things and patterns of Organization–is the actual driver behind urbanization.

Because people congregate in cities, the latter harness the densest and the most diverse information processing capacity. Not only does this relatively high information processing capacity ensure that they are able to maintain control over the channels through which goods and people flow on a daily basis, but their cultural (and, thus, information-processing) diversity also makes them into preferred loci of invention and innovation.

The super–linear scaling of innovation with city size enables cities to ensure the long-term maintenance of the information gradient that structures the whole system. It is due to a positive feedback loop between two of any city's roles. One the one hand, most flows of goods and people go through towns and cities. That confronts them most intensely with information about what is happening elsewhere, and this – again – enhances their potential for invention and innovation. But the same connections enable them to export these innovations most effectively – exchanging some part of their information processing superiority for material wealth. Cities are demographic centers, administrative centers, foci of road systems, but above all they are the nodes in the system where the most information processing goes on. As such, they are the backbone of any large-scale social system. They operate in network-based "urban systems" which link all of them within a particular sphere of influence. Such systems have structural properties that derive from the relative position all the cities occupy on the information-processing gradient, and in the communications and exchange networks that link them to each other (White, Chapter 5 in this volume). Although the role of individual towns in such systems may change (relatively) rapidly (Guerin-Pace, 1993), the overall dynamic structures are rather stable over long periods of time. In the long run, the organisation of human habitat in networks of cities reduces the uncertainties of a closed environment by relying on more distant resources as well as by creating new ones. There is a shift from a human ecology toward another way of structuring the planet, entangling territories (geographical structures based on continuity) in societal networks (that are based on connectivity).

The books of the Methodos series explore some of the new ways that emerge from the complex systems paradigm. Without entering into the debate about the possible emergence of a unified science of complex systems, we want here to develop a new theory of human social change, within a perspective that is informed by the recent developments of the complex systems paradigm. In this book, we will explain why we think that this paradigm can help us to identify the specificity of innovation and change in social systems.

Part I of this book: *From biology to society*, specifies how a new kind of organisation has emerged with the historical apparition of human societies. Although *Homo sapiens* is a biological species, whose individual elements do not in themselves differ from any other animal species in their biological organisation, and although social systems do share some properties with animal social organisations, two main radically new and distinctive features were created through the process that led to human social organisation. The first one is a self- monitored, directed (intentional) modality of social change. We shall demonstrate that this new kind of evolutionary driver is the result of the integration of new functionalities in social structures due to cultural processes. The second distinctive feature that is essential to our approach of social systems is that it is comprehensive: to shift from a static description of social structures to a dynamic one, we need to consider a variety of social interactions that are usually separated in disciplinary explanations of social systems. The modifications in social organisation that are directed at monitoring social changes, and that produce emergent patterns instantiated in organisations do affect a social system in every aspect and at all its levels of organisation. We describe how function, structure and process are affecting each other, and we build a dynamic, interactionist interpretation of the evolution of social systems.

In this attempt, it is important to determine which ingredients are necessary for developing a theory of human social innovation that is both general, and precise enough to be relevant. We believe that complexity theories are the necessary framework for developing a modern interpretation of change in complex systems. However, we question two principles that are part of the application of this theoretical approach to physical and biological systems. These are, firstly, the search for invariance and universality in processes. We demonstrate that human social change cannot be described in Darwinian terms, because something new has appeared, *i.e.* the fact that human societies are inherently responsible for their own innovation. This then leads us to question the applicability of the Darwinian approach of biological evolution to human social evolution, which we discuss in the first five chapters of this book.

Part II, *Innovation and urban systems,* and Part III, *Innovation and market systems,* develop examples of the application of these ideas and work out more precisely a number of aspects of this perspective. Urban systems are at the core of many important issues in contemporary societies. While cities concentrate a majority of the world population and human activities, the urban way of life may encounter limits that are increasingly perceptible in terms of the potential shortage of environmental resources (mainly energy, soil and water), in terms of organising a livable social mix, and in terms of managing local systems that are threatened by the unpredictable effects of their increasing connectedness to a multiplicity of networks through globalisation.

Sustainable development, social cohesion and territorial cohesion have become challenging issues for the monitoring of urban systems, in modern information societies as well as in developing and poor countries. It is thus essential to develop a proper understanding of urban dynamics in its complex articulation of a typical hierarchical structure with monitored but highly decentralised innovation processes that periodically renew the functionalities of individual towns and cities in increasingly better connected and wider-spread systems of cities. This enlarged (comprehensive) view of urban spatio-temporal evolution and its connection to social innovation is developed in Chapter 6. In biology, scaling laws have been identified as useful methodological tools reflecting the effect of energetic and geometric constraints on the development and structural organisation of living systems. Two chapters are dedicated to the application of this methodology on urban systems, using different approaches to determine to what extent further urban growth may depend on similar effects or not.

Markets are perhaps less easy to coin as complex social systems whose evolution requires a specific social input in a general theory of complex systems. Indeed, they are very often analysed within a unique disciplinary framework, and sophisticated mathematical models derived from the principles of economic theory are sometimes thought of as very successful descriptions of even the most capricious fluctuations in stock exchange evolutions that would open the way to quasi physical theories of these very decentralised and complex systems. However, we claim that such interpretations can only operate in specific contexts, where the social ingredients of what constitute the markets are clearly defined. If we want to understand real market evolution, we have to develop a broader theory of markets as social organisation. A major point we insist on is to demonstrate how social interaction is linked to the invention of new artefacts and their functionalities in social systems. This is done in three chapters of section three, including a reflection on the implications of our perspective for social policies favouring innovation.

Our complexity perspective has several methodological implications that we develop in Part IV of this book, *Modeling innovation and social change*. Models are the indispensable steps that enable a fruitful dialog between theory and empirical studies. In dealing with social change, we need abstract narratives that can identify what is really changing and what remains invariant over time in the evolution of social systems. Within the continuous and more or less rapid flow of social innovation that manifests itself in the production of new artefacts, new institutions, technological inventions, scientific breakthroughs, but also new social practices, collective representations and beliefs as well as new modes of social interaction, what are the features that are significant for interpreting social change? What are the decisive configurations in structure, function and process that are necessary for driving that evolution? Among those, what are the possible levers for intelligent monitoring, or partial control over the anticipated evolution? Models are useful tools for answering these questions.

The abstract description of social evolution can be translated into models. Mathematical and computational models help us to understand how social systems can share some features of their structure and evolution with other complex systems, as reflected for instance in structural power laws or scaling laws, whereas the parameters that are involved in these models take specific values which may imply a quite different qualitative evolutionary behaviour from natural or living systems. Because of that, we chose to develop not only analytical models of social change, but more flexible models that are no longer analytical but computational, including multi-agent models. These models allow the handling of both invariant features, including entities and rules whose properties represent stylised facts from observed empirical evolution, and creative aspects of social organisation when the nature of agents or artefacts is transformed through dynamic interactive processes. Although this can be partially modelled, the exogenous intervention of the modeller is still necessary to match such a creative evolution.

Another way in which computational models are helpful is that they enable the exploration of unexpected events and unforeseeable futures. Social changes do not operate in a predefined space where everything that might happen has been predefined. Mathematical models are not able to handle systems where something new can change the meaning of variables and parameters or create new categories. Whether the methods of artificial intelligence will be able to do so is still a matter of debate. We use AI here in modelling as a tool for exploring the limits between what can be endogenously produced from interactions within the model, and what has to be imported as exogenous knowledge by the model designer. Models are tools of random search in a space of not-yet-definite potential futures. Whenever possible, we have privileged data-driven simulation as a way of constructing models. This is the case for a variety of applications presented in section four (especially Chapters 13 and 17 on the dynamics of urban systems). The theory is injected in the model as abstract knowledge defining endogenous processes, and the results of simulation allow us to identify which specific processes have to be inserted from the outside to match observed or projected structures and functionalities.

As editors of this volume, we would not want to conclude this introduction without expressing our thanks to many people. First of all to the authors of the papers, who were our partners in the discussions and debates that led to these pages. Secondly to all those who helped us, at various times, to organize the many workshops and dealt with the inevitably complex administrative procedures, among whom we would like to mention particularly Irene Poli, Federica Rossi, Antoine Weexsteen, Martine Laborde, and the staff of the Santa Fe Institute. And thirdly to Callie Babbitt, who did all the final editing and typesetting of the manuscripts.

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