# Chapter 1
# Introduction

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Ontologies are increasingly recognized as essential components in many fields of information science. Ontologies were first employed in artificial intelligence, as a means to conceptualize some part of the real world. The first aim was to enable software system to reason about real-world entities. The CyC ontology (Lenat 1995) is typical of this perspective, it is comprised of several thousand concepts and tens of thousand facts, expressed as logical formulae. A second aim of ontologies was to provide a common conceptualization of a domain on which different agents agree. It is certainly this aspect of ontologies that triggered widespread interest in this knowledge engineering artifact in fields such as information system design, system integration and interoperation, natural language processing, or information retrieval. For instance, the Gene ontology (The Gene Ontology Consortium 2001) provides a common vocabulary to standardize the representation of gene and gene products.

Although the concept of ontology is now well understood and equipped with an array of theoretical and practical tools (there are currently several dozens of books on ontology engineering), the practical implementation of ontologies in a specific applicative context remains a challenging task. Moreover, the effectiveness

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or cost-benefit evaluation of ontology-based approaches still requires more research. One of the purposes of this book is to explore these questions in the urban domain.

## 1.1 Ontologies in Information Science

### *1.1.1 Defining Ontologies*

Over the last two decades, several definitions of the term ontology have been proposed (Gruber 1993; Guarino and Giaretta 1995). From a very general perspective, an ontology is a specification of some conceptualization of a domain. A conceptualization is an abstract model that represents the entities of a domain in terms of concepts, relations, and other modelling primitives. In principle, the specification of this conceptualization could take any form. However, the most commonly used ontological languages specify the meaning of concepts with some form of explicit definition. Thus an ontology is comprised of

- a representational vocabulary with different types of symbols (class names, relation names, etc.)
- a set of definitions that specify the meaning of the vocabulary

Each ontological language has its own types of symbols and definition expression language. For instance, in description logics the representational vocabulary consists of concepts, properties, and individuals; definitions are expressed as logical axioms that state, among others, equivalences, inclusions or exclusions between concepts as well as constraints on properties. The vocabulary of an ontology defined by UML class diagrams is made of classes, attributes, associations, etc. Definitions are graphically expressed by diagrams that can represent generalization/specialization or part/whole constraints between classes, as well as constraints on the associations between classes.

In this book, we take a rather broad view of ontologies. We admit that definitions can be expressed in a language that has no formal interpretation, in particular in natural language. Nevertheless, the expression must be sufficiently precise to enable the intended users (human or software agents) to *commit* to the ontology. By committing to an ontology an agent agrees to use the vocabulary in a way that is consistent with the definitions given in the ontology. It is clear that a software agent can only commit to an ontology expressed in a formal language, while a human being can commit to definitions expressed in natural language.

Following this view, it appears that some knowledge resources cannot be considered as ontologies. For instance, a thesaurus whose main purpose is to define an indexing vocabulary for a document corpus does not precisely define the meaning of each term. Hence, an agent cannot commit to meanings defined in this thesaurus. Conversely, other thesauri (such as the English Heritage Thesaurus) provide a much more precise definition (in English) for each term and organize them in a consistent generic-specific hierarchy. In this case a human agent can commit to these definitions and consider these thesauri as ontologies.

### *1.1.2 Current State of Ontologies and Ontology Engineering*

Recent years have witnessed a rapid increase in the number of publicly available ontologies.[1] These ontologies are not all of high quality and some are very restricted in scope. However, this shows that the development of ontologies is no more the preserve of large projects with significant funding. This is probably due to several factors, including:

- the availability of numerous books, tutorials, and courses on ontologies and ontology engineering;
- the semantic web initiative that stressed the importance of ontologies and lead to the development of the RDF/S and OWL web ontology languages. These languages have been widely accepted for the expression and interchange of re-usable ontologies;
- publicly available ontologies certainly create a kind of network effect, helping others to develop and share new ontologies;
- theoretical developments in description logics that lead to a much better understanding of theses logics. We know more precisely which logics have decision procedures for reasoning tasks, and what is the computational complexity of these procedures;
- work on reasoning algorithms resulted in practical reasoners that are highly optimized and applicable on large ontologies; and
- the availability of ontology engineering methodologies and associated tools such as editors, viewers, refactoring tools, etc. have popularized the ontology development process.[2]

Despite all these advances, ontology engineering is not yet an integral component of practical methods and tools in information engineering. For instance, the link between databases and ontologies still requires research and development work, as well as the integration of ontology-based reasoning in business processes.

## 1.2 Ontologies in the Urban Domain

Arguably, interest in ontologies for use in the urban domain was initially triggered by technological challenges related to interoperability of urban and territorial databases.

[1]For instance the Swoogle ontology search engine (http://swoogle.umbc.edu/) announces more than 10,000 indexed ontologies.

[2]The Protégé ontology editor has more than 100,000 registered users.

As information about urban areas and urban developments became more and more easily available and abundant, the need to interconnect different databases in order to perform complex tasks (traffic modeling, environmental management, urban forecasting etc.) appeared more urgent than ever. Since these databases are usually characterized by different purposes, spatial resolutions and quality of information, their interoperability obviously raised new demands in terms of ontology design and mapping. Difficulties in connecting different urban databases not only appeared in such complex modeling tasks, but also in apparently simple or routine tasks like the interconnection of spatial databases indexed by street names.

Reengineering of existing urban databases constituted another technological challenge that urgently called for urban ontologies. Actually, many of urban databases had been characterized by an incremental development since the diffusion of Geographical Information Systems amongst urban experts. Hence, it appeared that the conceptual schema of some of these databases were no longer consistent, given their progressive and unplanned evolution. A further upgrading of these databases to make them more easily available and to connect them with other data sources hence appeared impossible without a deep restructuring of their content. Given the magnitude and complexity of the task, ontology engineering was seen as a necessary step to manage both conceptual soundness and continuity with previous versions of the database.

European integration of databases constituted a third technological motivation for developing urban and territorial ontologies. It was mainly driven by growing demands related to cross-boundary integration of territorial databases, and the transposition of the INSPIRE European directive in all Member States. Such an exercise rapidly appeared far from trivial given existing discrepancies between national and regional databases. It especially revealed that some of these discrepancies, and especially terminological differences, often concealed serious ontology divergences.

Though, besides such real technological concerns, ontologies were rapidly considered as a conceptual challenge *per se* in the urban domain. Urban sciences have long been characterized by their hybrid nature, in that they usually convey different disciplinary backgrounds: architecture, law making, social sciences, construction, geography etc. Adopting a global conceptual framework, shared by all those disciplines involved in the urban environment, once appeared as neither realistic nor desirable. Though the lack of common grounds to exchange between these different world views should be considered as a major drawback in the circulation of knowledge between these disciplines as well as, and probably more importantly, between scientists, experts and daily urban practitioners.

Furthermore, urban sciences are characterized by the emergence and rapid diffusion of fuzzy concepts, like sprawl or urban sustainability, which by nature resist precise and generalized definitions. Such a profusion of neologisms should always be regarded with skepticism as they often hide a lack of conceptualization and scientific consensus. Still, it should also be acknowledged that they are also nurtured by new ways to frame urban issues, as in the case of urban sustainability, as well as rapid changes in the human-made environment, as in the case of sprawl. Such changes are usually driven by background forces, common to all cities, usually altered by local characters. To keep on the same examples, urban sustainability and sprawl are in some sense both universal and place-driven, which largely explains the difficulty to reach a consensus about related concepts in the urban domain.

Finally, if a number of models have been proposed to characterize urban structures since the early 1960ies and the seminal works of Forrester (1969), it should be acknowledged that the way cities are actually designed and produced by its actors, has hardly been formalized in the past. Here again, this may be related to place-based specificities of urban decision-making. Some authors further relate such a lack of conceptualization to the complex and unpredictable nature of communications in urban development project, while others would rightly raise concerns about the prescriptive nature of any conceptualization model in this domain. Still, the reluctance to propose tentative models to formalize communication flows between actors of urban development is certainly a serious impediment for the transformation and enhancement of existing decision systems. Here again designing urban ontologies has been viewed as a stimulating conceptual challenge in that it would force a clarification of communication means and purpose between the different actors involved in urban development: engineers, urban planners, constructors, architects, citizens, etc. As such, it appears as a way to engage a reflective exercise about the nature and conditions of urban development.

The need for comprehensive models of urban systems as an aid to future urban development has never been more urgent. The challenges policy makers and practitioners face in this turbulent period of human history demand new understandings and new approaches. The emerging "low carbon" agenda, together with the requirements of social and economic sustainability, all suggest systemic approaches, in which we can expect the explicit development of ontologies to play a major role.

Interestingly these two ways to frame the issue, as both a technical and a conceptual challenge, once met in the COST Action C21, which specifically aimed at prospecting the potential of ontologies as a way to enhance communications in urban development projects.

## 1.3 Structure of the Book

The first part of the book is a presentation of the fundamental concepts and issues of ontology engineering. An introduction to ontologies and ontology engineering provides a detailed view of the different types of ontologies, according to their level of formalization and their purpose. This introduction also presents a typology of the ontology design approaches. The subsequent chapters address issues in ontology engineering that are particularly relevant in the urban domain: using ontologies to ensure interoperability; dealing with heterogeneity and differences in viewpoints; and dealing with multilingualism in ontologies.

The second part focuses on methods and tools to apply ontology engineering in the urban domain. It covers the geographical aspect of urban ontologies; the interconnection of urban models through ontologies; the interconnection through different representation scales; the development of urban knowledge based systems; and the creation of ontologies from existing urban knowledge resources.

The third part is a collection of case studies in the construction and use of urban ontologies. Each case study is described using a common template to facilitate comparison and to ensure a suitable coverage of each case. The cases are drawn from a wide variety of domains loosely related to urban development. Their diversity—ranging from building information models to urban scale public participation—underlines the potential for widespread application of ontology engineering. This part concludes with an overall analysis that highlights lessons learned and questions to solve.

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