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A Handbook of Principles, Concepts and Applications in Information Systems

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edited by

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Dedicated to

To my wife Janie, my children Kristi, Kristin and Krissie and my parents
T.S. and Sushila Visvanathan

– Raj Sharman

To Sujata, Anant, and Aseem for your love, support, inspiration, and
patience

– Rajiv Kishore

To the countless individuals who have helped, guided and shaped my life
and continue to do so

– Ram Ramesh

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Foreword

Ontology, or the nature of being, has been a focal area of study in the philosophical disciplines for a long time. Interpreted simply, the term ontology refers to the question "what kinds of things exist?" to a philosopher, while a computer scientist grapples with the question "what kinds of things should we capture and represent?" Together, research on the two questions yield a broad framework for the analysis of a discourse universe, its representation in some abstract form and the development of organizations and systems within the universe.

The philosophical perspective on ontology provides a description of the essential properties and relations of all beings in the universe, while this notion has been expanded as well as specialized in the fields of computer science and artificial intelligence. The AI/CS communities now use this notion to refer to not one but multiple ontologies. In the AI/CS perspective, an ontology refers to the specification of knowledge about entities, and their relationships and interactions in a bounded universe of discourse only. As a result, a number of bounded-universe ontologies have been created over the last decade. These include the Chemicals ontology in the chemistry area, the TOVE and Enterprise ontologies for enterprise modeling, the REA ontology in the accounting area, organizational knowledge ontology in the knowledge management area, an ontology of air campaign planning in the defense area, and the GALEN ontology in the medical informatics area.

Of late, however, there is a growing recognition that ontological principles and concepts need not be restricted to the traditional domains of knowledge inquiry, and can be fruitfully applied to and developed further in various fields within the broader information systems area. This has led to the notion of *ontology-driven information systems (ODIS)*, a concept that, although in preliminary stages of development, opens up new ways of

thinking about ontologies and IS in conjunction with each other, and covers both the structural and the temporal dimensions of IS.

In the structural dimension, ontologies can provide mechanisms for structuring, storing and accessing generic IS content including database schemas, user interface objects, and application programs that can be customized and integrated into a functioning IS. Unlike the well-established data modeling paradigms, the structural foundations of ontological systems are still in infancy; there is a growing need for a unified theory of structural representations of ontologies. Some of the key research questions in this dimension include: What representational formalisms for ontologies are needed? How are these distinguished from the traditional relational, predicate-based and object formalisms? Can algebras and calculi be developed for specific ontology representation formalisms? How can ontologies yield efficient frameworks for systems design? There are many more important questions in this dimension.

In the temporal dimension, ontologies can guide the development of new information systems by helping analysts and designers choose appropriate processes, algorithms, rules, and software components depending upon their needs. It has also been suggested recently that ontologies, frameworks, and systems are essentially knowledge artifacts at different levels of knowledge abstraction and, therefore, systems can be generated from bounded-universe ontologies through specialization and combination. It also appears that the emerging paradigms such as web services and the semantic web will enable the large-scale development, deployment, and sharing of ontologies and ontology-driven information systems. Some of the key research questions in this dimension include: How can both the static and dynamic elements of a universe be captured in an ontology? Can ontologies be sound and complete? Can ontologies be verified and validated? What are the relationships between ontologies and the systems development life cycle? What theories of ontologies are needed for ontological system integration, interoperability of ontologies and knowledge discovery through ontology mining? Can ontologies be used in organization design, besides their well known applications in systems engineering? And there are numerous other questions.

The primary objective of this book is to mobilize a collective awareness in the research community to the leading and emerging developments in ODIS, and consequently, highlight the enormous potential of ODIS research to both fundamentally transform and create innovative solutions to several problems in various domains. This book is a compendium of some of the leading research of the community working in various fundamental and applied disciplines related to ODIS. These contributions deal with the design, technical, managerial, behavioral, and organizational aspects of

ODIS. They clearly demonstrate the synergies derived from cross-disciplinary efforts in ODIS research and also open up the numerous challenges and opportunities in the road ahead.

This book contains a total of 32 leading-edge research contributions presented as chapters. These chapters are organized into the following broad themes: *Foundations of ODIS, Ontological Engineering, ODIS Architectures,* and *ODIS Applications.* These four themes together describe the state-of-the-art in ODIS and give a complete perspective on the problems, solutions and open research questions in this field. We briefly outline these contributions in the following discussion.

Foundations of ODIS

The foundations of ODIS are addressed in Chapters 1–6. Chapter 1 provides an introduction to ontologies and a justification of their need in various domains. They expound on how the concept of ontology has expanded from Philosophy into Computer Science and is an excellent introduction to those who are new to the area. Chapter 2 discusses how taxonomies and ontologies can help in making sense of huge amount of content that gets generated across the locations in different languages and format. Chapter 3 illustrates how an ontological evaluation of business models can be used to compare them for equivalency of representation of business requirements, especially when re-engineering legacy systems into component-based information systems.

The semantic web is a mechanism of representing information on the web in a form that makes it processable by machines on a global scale. Semantic Web based applications are being developed in all disciplines, although the area is still in its infancy. Chapter 4 provides a detailed introduction to the use of ontologies, ontology languages and editors in the context of the semantic web and highlights their advantages through real-world applications. Chapter 5 examines the differences between positivism and non-positivism ontologies and concludes that those differences are indeed irreconcilable. Interestingly, this chapter studies the relationships of epistemology and methodology with ontology and concludes that there are clear epistemological and methodological consequences of the ontological divide, but these are less clear-cut than the ontological opposition. This opens up the pragmatic implications of this ontological divide on IS research and raises the question of whether a tolerant coexistence of the two approaches is feasible within IS research. Finally, Chapter 6 argues that a large number of moral and ethical issues, such as privacy, intellectual property, access to data, and digital divide, are related to and even created by the use of information technology. This chapter proposes that these ethical

and moral issues can be viewed through the lens of responsibility in information systems and examines this notion of responsibility through positivist ontology as well as ontology of life-world which represents a reality that is created by intentional perception and hermeneutic interaction.

Ontological Engineering

The principles and techniques of Ontological engineering in the context of ODIS are addressed in Chapters 7–14. Chapter 7 presents an ontological engineering approach to knowledge-intensive Case Based Reasoning (CBR) systems development. This chapter addresses knowledge acquisition through cases, knowledge representation, ontology development and systems engineering. Chapter 8 presents an overview of the state-of-the-art research on the subject of applications of Model Development Architecture (MDA) standards for ontology development, including a discussion on similarities and differences between MDA languages and semantic web languages. A new ontology language M-OWL that supports an ontology designed for multimedia applications is presented in Chapter 9. M-OWL is an extension of the standard ontology language OWL. Chapter 10 addresses a basic problem in implementing ontology-based information systems, that of ontology growth and evolution through revisions. New knowledge, essentially justified true beliefs, that needs to be incorporated in an ontology for its growth may contradict the current knowledge stored in the ontology in terms of definitions and agreements. When this happens, the ontology may need to be revised to reflect the changes. This chapter shows that belief revision theory provides a way to revise an ontology ensuring that new knowledge does not cause inconsistencies with existing knowledge when it is incorporated in the system, and develops a three-phase ontological reengineering methodology based on this theory.

Knowledge changes over time and domains evolve. The ontology supporting domain knowledge has to keep up with this growth. Chapter 11 presents a framework for representing ontological evolution over time and provides an ontology developer with an intuitive change model for expressing local ontological changes in a declarative way. Chapter 12 develops an interesting incremental ontology population methodology that exploits machine learning techniques to tackle the problem of ontology maintenance. This chapter also includes experimental results to establish the applicability and effectiveness of the proposed methodology. This chapter is an excellent complement to Chapter 11, and together they present effective tools for ontological engineering. Chapter 13 develops a tool called MnM that helps during the ontology maintenance process. Using natural language processing, information extraction, and machine learning technologies, MnM uses information extracts from texts and populates an ontology. MnM

has the potential to become an important part of standard ODIS repertoire, given its integrated web-based ontology editor, open APIs to link to ontology servers and integration with the information extraction tools.

The last chapter in this cluster (Chapter 14) deals with the selection of an appropriate requirements elicitation (RE) technique in ontological engineering from a huge set of such methods and their variations. This issue has become very important due to the development of numerous new and innovative RE techniques used by various researchers and practitioners. Chapter 14 creates an ontology describing the context for requirements elicitation, elicitation techniques and their selection criteria, key characteristics of elicitation techniques and their similarities and differences. This chapter presents an approach that can be used by systems developers for selecting an appropriate elicitation technique in a given context.

ODIS Architectures

A collection of ODIS architectures in a variety of contexts is presented in Chapters 15–24. Chapter 15 examines the evolution of knowledge intensive business processes and develops an architecture for systems supporting such processes using ontology principles. The central idea here is design automation of high-end systems that are typically needed in knowledge management. Chapter 16 develops an approach to creating an object model from a problem domain description by using ontologies as a basis for object identification and abstract data modeling. This chapter yields a nice framework for conducting the analysis and conceptual modeling phases of systems design leading to the development of object-oriented architectures in a variety of domains. Chapter 17 develops interesting insights into the ontology metaphors. The notion of ontology is used to discover and define the source domain knowledge in terms of metaphors. Integrating the Conceptual Mapping Model between a source domain and its target domain with an ontology-based knowledge representation, this chapter demonstrates how a conceptual metaphor analysis could lead to automated architectural designs. Chapter 18 introduces the notion of Knowledge Collective, which is a realization of Expert agents who may need to have their own ontologies and to work together as a team to tutor students. A multi-layered, multi-agent framework for developing and maintaining intelligent knowledge bases that can be used in areas such as Intelligent Tutoring Systems is developed in this chapter.

Chapter 19 argues that hypermedia documents are essentially knowledge assets of an organization and uses a knowledge management ontology to integrate technical hypermedia concepts with organizational information systems. The core elements of the hypermedia ontology are derived from the

existing Labyrinth model while the knowledge management concepts come from Holsapple and Joshi's knowledge management ontology. The resulting ontological framework provides ground for the development of ontology-based Information Systems in which hypermedia assets are managed. Chapter 20 introduces an architecture and ontology model for an ontology-enabled database management system. This chapter also introduces many extensions to the RDF/S-based ontology models that are emerging as standards, and provide a graph-based abstraction for the model.

Designing for interoperability among system architectures using underlying ontological principles is the focus of Chapter 21. This chapter addresses the scope and limitations of a web service choreography standard in providing standardized descriptions of business processes both in terms of process flow and control flow. Focusing on the set of limitations arising out of a lack of a general ontology for enterprise systems interoperability domain, this chapter develops a comprehensive ontological representation model for such descriptions.

Dynamic discovery and invoke ability are very important components of Service Oriented Architecture (SOA). Chapter 22 presents a context-aware ontology selection framework, which allows an increase in precision of the retrieved results by taking the contextual information into account. The main component of the context-aware ontology selection framework is the matching algorithm that attempts to find a semantic match between a declarative description of the service being offered and the service in demand. Chapter 23 argues that a focus on users is crucial in the design of a knowledge management system (KMS) to account for the heterogeneity of users, differences in their responsibilities, their different domains of interests, their different competencies, and their different work tasks that are to be handled by the KMS. Emphasizing the role of user models, this chapter proposes an ontology-based user modeling approach that manages extended user profiles containing not only user competencies and their preferences but their behaviors as well including types of activity, levels of activity, and levels of knowledge sharing. User modeling addresses two important user needs: a need for enhanced support for filtering and retrieving the knowledge available in the system, and a need to better manage the tacit knowledge that is generally believed to be the more important types of knowledge.

Finally in this cluster of chapters, Chapter 24 presents the architecture of a personalized search system. This system employs user profiles, the browsing-history and profiles built from system interactions to improve the performance of search engines. This chapter provides an insightful discussion on a variety of mechanisms for automated profile creation leading to several open issues in this process.

ODIS Applications

A set of important and emerging ODIS applications is presented in Chapters 25–32. Chapter 25 presents an ontological approach to design information systems that support supply chain operations. By separating domain knowledge from IS solutions, an ontology-based application architecture that effectively complements its three other components – interface, management, and knowledge gathering is developed for the supply chain integration context. Chapter 26 discusses the problem of interoperability in the manufacturing parts arena. This chapter argues that while imposing a standard terminology and classification system for manufactured components by an organization on its suppliers would increase interchange and interoperability, this may not be always feasible due to resistance by the suppliers. To overcome this problem, this chapter proposes a three-phase methodology for developing a harmonized ontology of an enterprise's product models in use. This methodology has been applied and tested in the Intelligent Manufacturing Systems (IMS) SMART-fm program (www.ims.org) and European ATHENA project (www.athena-ip.org) under real industrial environments. Chapter 27 classifies the concepts of ADACOR (ADAptive holonic COntrol aRchitecture) ontology for distributed manufacturing systems using the DOLCE (Descriptive Ontology for Linguistic and manufacturing scheduling and control environments. This ontology is conceptually transparent and semantically explicit due to the use of a sound foundational ontology and formal semantics and is appropriate for information communication, sharing, and retrieval in manufacturing environments.

Chapter 28 presents the Babylon Knowledge Explorer (BKE) system which is an integrated suite of tools and information sources to support the prototyping and implementation of ODIS and several other ontology-enhanced knowledge applications. Chapter 29 investigates the development of a software-based ontology within the context of a rural wireless emergency medical (EMS) services. Using an inductive, field-based approach, this study devises and tests a new ontology-based framework for wireless emergency response in rural Minnesota. This ontology is expected to yield effective solutions to several technical and non-technical problems in EMS deployment, especially in rural settings.

Smart card (SC) technology is emerging as a technology that offers a solution for the current problems of secure communication and data handling with reasonable privacy by fulfilling simultaneously the main demands of identification, security, and authentication besides the functions of the main application (e.g., payments). Chapter 30 uses the notions of ontology in this area and develops a General Reference Architecture for Smart Card systems

(GRASC) that can help address some of the problems in configuration, reconfiguration, interoperability, and standardization of smart card systems. Chapter 31 develops the ontological foundations of Mobile Surveyor, a model-based monitoring system that provides a novel approach to software monitoring by incorporating data models throughout the monitoring process. Focusing on the construction and deployment of the underlying concept ontologies, this chapter also develops a design environment for ontology development and knowledge-base querying and management. The last chapter in this set, Chapter 32 integrates current journalistic standards with existing top level ontologies and other metadata-related standards to develop an ontology for journalistic applications.

Putting It All Together

This book is a significant contribution to research on ontologies, ontological engineering and ODIS development. With its foundations in the fields of philosophy, computer science, artificial intelligence and information systems, the domain of ODIS is rapidly expanding due to numerous multi-disciplinary efforts in various research communities over the years. Our attempt has been to spotlight the themes emerging in ODIS research and weave them into a tapestry of thought giving ODIS a unique identity in the arts and sciences. Research on ODIS holds tremendous promise for future advances. We hope this book will give the research communities a refreshing perspective on ODIS and a new view of the future. We also expect this book to trigger innovative thought processes that will open up significant new domains in ODIS research. Numerous open research questions, challenges and opportunities can be found throughout this book and we hope this will stimulate significant research over the years.

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