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Article

Conceptual Modelling and Representation of Domains of Human Action: Contributions From Information Science/Knowledge Organization

Carlos H. Marcondes[1,2,*]

[1]PPG-GOC/UFMG - Postgraduate Program in Knowledge Management and Organization, Minas Gerais Federal University, Belo Horizonte, MG 31270-901, Brazil
[2]PPGCI/UFF - Postgraduate Program in Information Science, Fluminense Federal University, Campus do Gragoatá, Niterói, RJ 24210-200, Brazil
*Correspondence: ch_marcondes@id.uff.br (Carlos H. Marcondes)
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Prof. Carlos H. Marcondes is PhD in Information Science, full Professor at Federal Fluminense University, Rio de Janeiro, Brazil, where he is coordinator of the ROCad - Knowledge Representation and Organization in Digital Environments - Research Group. He was Visiting Professor at Minas Gerais Federal University, Minas Gerais, Brazil. He is Associated Researcher of the Brazilian CNPq – the National Council for Scientific Development – and of the Complutense University, Madrid, Spain. He was "chair" of the 1st Ontology Research Seminar in Brazil, UFF, which today is the series of ONTOBRAS events. He was consultant of several projects of KOSs in Heritage sector.

Abstract

The current Big Data phenomenon bears similarities to the so-called information explosion that gave rise to Information Science (IS) in the 1950s. To discover, access, interpret, make sense of and reuse the growing volume of digital data, conceptual modelling has emerged as an essential discipline and is now a fundamental area of research. Conceptual modelling originated in Computer Science (CS), specifically within the field of databases. However, IS and Knowledge Organization (KO) have long developed theories, methodologies, and best practices for constructing information and knowledge organization systems that can be applied to conceptual modelling and ontological analysis. What are the contributions of IS/KO to conceptual modelling? This article is a position paper that presents and discusses the contributions of IS and KO to the modelling and ontological analysis of domains of human action. The focus is on the work of authors such as Hjørland, Ranganathan, and Dahlberg. Similarities and differences between conceptual modelling in CS and IS/KO are examined, with particular emphasis on the growing convergence between Information Science/Knowledge Organization and Computer Science.

Keywords: conceptual modelling; domain analysis; ontological analysis; Information Science; knowledge organization; Hjørland; Ranganathan; Dahlberg

1. Introduction

Conceptual modelling of human domains of action is today a key application and research area. Since the advent of database management systems in the 1970s, conceptual modelling has evolved into a pivotal field, attracting contributions from disciplines beyond Computer Science (CS), including systems engineering, formal ontology, and Information Science (IS)/Knowledge Organization (KO).

The current Big Data phenomenon—often described as 'information deluge', 'data deluge' or even a 'tsunami of data' (Hey and Trefethen, 2003)—is reminiscent of the 'information explosion' identified by Bush (1945), which led to the development of IS and KO. In response to that earlier explosion, KO developed Knowledge Organization Systems (KOS) to work alongside Information Retrieval Systems (IRS)—computerised databases containing records of scientific documents. These KOSs, such as the 'information retrieval thesaurus' (Dextre Clarke and Zeng, 2012), help control and standardise the meaning of natural-language terms used both for indexing IRS records and for formulating user queries. While conceptual modelling is a topic of intense research in CS, explicit discussion of it remains comparatively rare in the IS/KO literature.

This article is a position paper that aims to review, present and discuss the contributions of IS/KO to the modelling of domains of human action. It focuses, among other authors, on Hjørland's domain analysis, Ranganathan's Faceted Classification theory, and Dahlberg's concept theory.

The article is organized as follows. After this introduction, Section 2 discusses similarities and differences between modelling domains in CS and in IS/KO. Section 3 examines contributions from IS/KO, with emphasis on the work of Hjørland, Ranganathan, and Dahlberg. Section 4 discusses the claims and findings advanced in the previous sections. Finally, Section 5 presents the conclusions.

2. Differences and Similarities Between Modelling Domains in CS and IS/KO

Conceptual modelling has traditionally been a core research and inquiry area within CS (Thalheim, 2018). With the emergence of databases and ontologies, it has also increasingly become an area of interest in IS/KO. According to Thalheim (2018, p. 9), the concept of conceptual modelling has spread beyond computer science and engineering to encompass a wide range of scientific fields. He also notes that "there is no common notion of this concept yet".

In their 2020 review, Guarino, Guizzardi and Mylopoulos examine the evolution of conceptual modelling since its inception in the 1960s. They address fundamental questions concerning the nature of this activity and the definition of a conceptual model. They provide a broad overview of the development of conceptual modelling, covering areas such as databases and software engineering, artificial intelligence, information systems engineering, object-oriented models, and business process management. According to the authors, conceptual models are 'explicit descriptions of mental models. They are information objects (typically encoded in physical supports such as computer memories) that rely on a Modelling Language to describe any aspect of a domain of interest for purposes of understanding and communication' (Guarino et al., 2020, p. 4).

In this sense, a database can be understood as a representation of a domain of reality within a computer environment. Chen characterises conceptual modelling as the construction of 'models that identify and structure the core components and interconnections in a domain to facilitate better system design and integration' (Chen, 1976). Other definitions emphasise its representational function: 'Conceptual modelling is the representation of concepts, their relationships and constraints, with the aim of depicting how a domain functions at an abstract level' (Bork et al., 2019). According to the Conceptual Modelling website, 'conceptual modelling is about describing the semantics of systems at a high level of abstraction'. This explicit emphasis on semantics represents an important point of convergence with IS/KO.

Barry Smith has emphasised the close relationship between conceptual (ontological) modelling and classification, or taxonomy, a traditional application area in IS/KO.

> Philosophical ontology is a descriptive enterprise. It is distinguished from the special sciences not only in its radical generality but also in its primary goal or focus: it seeks, not predication or explanation, but rather taxonomy. (Smith, 2006, p. 5)

The American philosopher John Searle (2006) argues that social reality gives rise to a 'social ontology' that constrains human life as much as a meteorological phenomenon, a physical barrier, or the expression of a gene that creates a pathology. An example of this would be a law. Representing the domains of human action created by social and economic life—such as agreements, conventions, laws, and power relations—in computer environments is one of the most notable application areas of conceptual modelling. According to Akoka et al. (2024) 'Conceptual modelling is an important part of the development of information systems because it focuses on the application domain.'.

More recently, IS/KO scholars concerned with domain modelling have also proposed expansive definitions of what constitutes a domain:

> … a domain is any area of knowledge or field of study that we are interested in or that we are communicating about that deals with specific kinds of entities. They include conventional fields of study (e.g., physics, mathematics), applications of pure disciplines (e.g., engineering, agriculture), any aggregate of such fields (e.g., physical sciences, social sciences), or can even capture knowledge about our everyday lives (e.g., music, movies, sports, recipes, tourism). "Domains provide a bird's-eye view of the whole field of knowledge, offer a comprehensive context" (Giunchiglia et al., 2014, p. 50)

CS has employed conceptual modelling, since Peter Chen's seminal paper in 1976, for planning and developing computational systems, particularly databases—that is, formal representations of domains in computer environments. CS was the first field to use conceptual modelling as an intermediate phase in computer systems development. This intermediate phase is justified by the high cost of writing and modifying computer programs and designing databases. An intermediate artefact—the conceptual model—allows the correctness of a system design to be verified and validated with future users before implementation. The communicative function of a conceptual model is also emphasized by Thalheim (2018, p. 11): "A conceptual model of an application is the model of the application that the designers want users to understand. By using the application, talking with other users, and reading the documentation, users build a model in their minds of how to use the application." He further stresses domains as sources of contextual information for conceptual modelling, describing them as instruments "commonly accepted by [their] community of practice within some context" (Thalheim, 2018, p. 9). Conceptual modelling is therefore considered a key phase in system development. Such aspect is emphasized in an up-to-date review including topics, themes, and technology trends: 'Conceptual modelling is an important part of information systems development and use that involves identifying and representing relevant aspects of reality.' (Storey et al., 2023, p. 1).

Since Chen's paper conceptual modelling in CS has evolved into a comprehensive methodological framework for modelling not only databases but entire computer systems. This framework includes domain modelling using class diagrams, requirements modelling in the form of use case diagrams, and system modelling and specification through activity diagrams, sequence diagrams, component diagrams, and deployment diagrams (Unified Modeling Language, 2025).

By contrast, KOS—such as subject headings, thesauri and taxonomies—originated in printed form in the late 19th and 20th centuries (e.g., Library of Congress Subject Headings (LCSH), dating to 1898, and Medical Subject Headings (MeSH; 2026) from the U.S. National Library of Medicine, dating to 1960), long before the emergence of computers and database systems. The first attempts to develop computerised KOS date to the 1970s, when computers and databases began to be used in the development of catalogue systems and KOS. The earliest online bibliographic information retrieval system was MEDLINE in the 1970s (Norman, 2025).

A notable milestone in the application of conceptual models in IS/KO was the publication of the IFLA's Functional Requirements for Bibliographic Records (FRBR) in 1998 by a study group from the IFLA Cataloguing Section. According to FRBR (IFLA, 1998, p. 9), "The methodology used in this study is based on an entity analysis technique that is used in the development of conceptual models for relational database systems." FRBR established the functional requirements that bibliographic records should fulfil within a cataloguing system, specifying *users' tasks* when interacting with an automated bibliographic catalogue. The identified user tasks were as follows:

- to find entities that correspond to the user's stated search criteria...;

- to identify an entity...;

- to select an entity that is appropriate to the user's needs...;

- to acquire or obtain access to the entity described.... (IFLA, 1998, p. 82).

The FRBR conceptual model represents different levels of abstraction of bibliographic entities—such as works, expressions, manifestations, and items—along with their interrelationships. Its objective is to bring together a work and all related, less abstract entities, such as different translations and editions typical of the publishing industry, as well as the individual items acquired by a library and presented in its catalogue.

Thus, the FRBR model represents elements that are broadly comparable to those found in the Unified Modeling Language (UML) use case diagrams (users' tasks) and class diagrams, namely, the entities in a bibliographic catalogue and the user's (case) tasks.

Following the publication of IFLA's FRBR, the museum community introduced the CIDOC Conceptual Reference Model (CIDOC CRM). The CRM provides a high-level representation of entities within heritage domains and aims to integrate and mediate heterogeneous sources typical of the cultural heritage sector, as different databases. The most recent standard for thesaurus construction, ISO 25964: Information and documentation—Thesauri and interoperability with other vocabularies (Will, 2012), also employs a conceptual model to illustrate the entities and relationships that exist within a thesaurus. In 2017, the archival community released the Records in Context Conceptual Model (International Council on Archives, 2023). Across the archives, libraries, and museums, communities use several local and ad hoc standards for description. Conceptual models serve as abstract, high-level representations of these domains and play a crucial role in facilitating standardisation and interoperability.

The product of KOS development is an artefact such as a classification system, taxonomy, thesaurus, or site information architecture. In traditional KOS practice, there was no explicit conceptual modelling phase or intermediate artefact such as a conceptual model. According to Mazzocchi (2018, p. 57), KOS are "semantic tools", emphasizing their nature as artifacts designed for semantic purposes, in line with several definitions from computer science. The contributions of IS/KO have therefore focused on the effective construction of such artefacts to support the retrieval of document records stored in databases.

When ontologies emerged in the 1990s as a characteristic form of computational implementation of KOS in the 1990s, Vickery argued for the need for conceptual modelling in the development of such systems. He noted that

> Knowledge engineering suffers from a lack of formal tools for understanding domains of interest. Current practice relies on an intuitive, informal approach for collecting expert knowledge and formulating it into a representation scheme adequate for symbolic processing. Implicit in this process, the knowledge engineer formulates a model of the domain, and creates formal data structures (knowledge base) and procedures (inference engine) to solve the task at hand (Vickery, 1997, p. 277).

As ontologies became a key component of the Semantic Web vision (Berners-Lee et al., 2001), and as the need for ontology modelling and development methodologies increased, the similarities between ontologies as computational artefacts and traditional KOS became increasingly evident. Authors such as Souza et al. (2012), in their analysis of the expressiveness of KOS, identify ontologies as the most expressive form of KOS. For such computational representations to adequately reflect reality, they must be ontologically consistent. This concern has given rise to the growing convergence between conceptual modelling, ontologies, and ontological analysis (Guizzardi, 2005). Guarino (1997, p. 57) defines formal ontology as dealing with 'formal distinctions between the elements of a domain, independently of their actual reality'. Formal ontology has thus become a key discipline in domain modelling, providing methodological guidance for identifying the general categories to which entities in a specific domain belong. These general category systems underpin top-level ontologies such as Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE; Borgo et al., 2022), Basic Formal Ontology (BFO; Smith, 2003), and Unified Foundational Ontology (UFO; Guizzardi et al., 2015). This process is commonly referred to as ontology alignment. It is important to note how research in formal ontology, originating largely within CS, has also contributed to the improvement of traditional KOS (Bodenreider et al., 2007; Smith et al., 2007).

In the context of developing domain ontologies, or ontological engineering, identifying and using foundation or top-level ontologies is considered a pivotal methodological step. "The adoption of a top-level ontology is a methodological step to guarantee a high degree of semantic interoperability among domain ontologies" (Guarino, 1998, p. 6). This phase is also emphasized by Gómez-Pérez et al. (2004, p. 124): "Process 2. Preliminary design based on relevant top-level ontological categories".

IS/KO has long investigated the nature of information and its relationship with knowledge. The pioneering article by Shannon and Weaver (1949), which proposed a model integrating communication and information, has been widely discussed within IS/KO, and this topic has also been taken up in CS. In parallel, CS has proposed modelling information through the Information Artefact Ontology (IAO) (Ceusters, 2012). IS/KO has identified at least three concepts of information: information as a cognitive process, information as objects that act as carriers of information, and information as a socially constructed and agreed-upon phenomenon (Buckland, 1991). These three conceptions were often treated as mutually exclusive; however, more recent proposals have sought to integrate and reconcile them (Gnoli, 2008).

The ultimate objective of IS/KO is to provide access to documents. In this context, IS/KO has developed a refined understanding of information, viewing it not merely as an artefact or carrier of information. The FRBR model (IFLA, 1998) conceptualizes a document instance—a carrier of information—as the concrete realization of an abstract entity, the work, which represents a creation of human culture, such as Hamlet by Shakespeare. A work may have a more concrete linguistic expression in a particular language and a manifestation in the form of a specific edition, which is realized through multiple items, such as individual documents or information artefacts, as conceptualized in the IAO. Additionally, Gnoli argues that a work may acquire independence from its creators and persist as an autonomous entity within human culture. Gnoli (2008, p. 85) refers to such entities as "mentefacts".

IS/KO research makes important contributions to conceptual modelling. In their article, 'Information as Ontologization', Saab and Riss (2011, p. 2246) contrast sense-making (individual) with meaning-making (collective and social), defined as the shared interpretation of a domain by its agents, which must be captured through conceptual modelling. The authors claim that:

> Though sense-making is a process of an individual, it also takes place in a shared environment that produces similar experiences in cognitive agents who are furthermore embedded in similar sociocultural contexts. (Saab and Riss, 2011, p. 2242), and

> It is this process of creating a mutual cultural understanding of patterns within our experience that we call meaning-making. It is sense-making on a sociocultural level, where the awareness of others' knowledge capacity allows us to refine the sense of a thing into meaning (Saab and Riss, 2011, p. 2242).

3. Contributions to Modelling Domains From IS/KO

IS/KO has developed theories, methodologies, and best practices for constructing information and knowledge organization systems that can be used in ontological analysis and conceptual modelling. This section outlines these contributions, emphasizing the work of authors such as Hjørland, Ranganathan, and Dahlberg. Such contributions are presented in the following sequence. First is Hjørland's contribution, which does not focus directly on conceptual modelling but instead emphasises domain analysis (Hjørland and Albrechtsen, 1995, p. 400). This contribution stresses that domains are essential to conceptual modelling because they are sources of meaning. Second is Ranganathan's pioneering contribution. He was the first to propose organizing a classification scheme into the idea (i.e., conceptual), verbal, and notational working planes (Ranganathan, 1965, p. 4). Third is Dahlberg's seminal contribution (1977, 1981, 1982) in the form of Concept Theory, which provides a detailed methodological framework for domain modelling through concept analysis and the establishment of categorical relationships. This framework has proved useful in the initial stages of conceptual modelling.

3.1 On Conceptual Representation and Modelling in IS/KO

When developing a computational ontology, the main objective in CS is to enable computational and deductive reasoning about the knowledge representation of a domain, that is, a computational ontology. By contrast, the main objective of IS/KO is to model and represent objects within that domain, most often documents or objects that have been transformed into documents (Briet, 1951), that is, "objects-as-signs" in semiotics (Buckland, 1998, p. 221), which have subjects among their properties.

Such representations are components of finding aids—KOS—used to locate e.g., a book, by providing its title, author, date of publication, subject, or other attributes. Once retrieved and displayed to the user, these representations allow the user to decide whether the item is relevant and of interest for access and reading.

Another key aspect of representation and modelling practices in IS/KO is that, to address the problem of locating books in a library, these activities are specialized into descriptive (or cataloging) and thematic representation (or indexing). This specialization reflects the historical focus of IS/KO on documents.

Typically, practices of descriptive and thematic metadata assignment are local, ad hoc, and lack standardization across heritage institutions. Such representation practices differ markedly from those commonly used in ontological modelling in CS (Guizzardi et al., 2018). Heritage institutions, for example, use conceptual models to standardize concepts, terms, and descriptions of objects in their collections to achieve interoperability across databases and to provide multiple access points to Cultural Heritage records, rather than to support formal reasoning. In the example discussed by Stead (2008, slide 14), a religious object—a Holy Bread Basket—is classified both as a Canister type and as an Ecclesiastical item. Classification and taxonomic schemas thus function as retrieval aids rather than reasoning tools. This dual inheritance supports retrieval and accommodates the integration of local cataloguing practices. Curators and information professionals play a fundamental role in providing context to heritage objects through the assignment of rich metadata. Such primary curatorial work creates access points that facilitate user access.

Within Library and Information Science practice, access points *are* frequently *not* intrinsic attributes of the object itself but contextual and cultural properties assigned to the object's catalogue record by information professionals to facilitate user access and retrieval. These are generally referred to as facets, a concept introduced by the librarian pioneer Shiyali Ramamrita Ranganathan.

Within IS/KO, interpretation of objects, events, and historical traces plays a fundamental role. There may be diverse and even conflicting interpretations of the same object or past event (Campos, 2018). Unlike the natural sciences, there are relatively few consensual paradigms; instead, multiple perspectives and interpretative frameworks coexist. Curators, as interpreters of past events, play a central role in this process. This aspect is emphasized, for example, by the CRM (2024, p. 10), which highlights the role of such databases as sources for scientific research in the Digital Humanities: "The term 'scientific documentation' is intended to convey the requirement that the depth and quality of descriptive information that can be handled by the CRM should be sufficient for serious academic research."

Conceptual modelling in IS/KO is therefore mainly understood as representing domains in order to create thesauri, classification schemes, taxonomies, and so on. These artefacts act as finding aids, and the representational work performed by information professionals aims to provide a broad range of access points. At the same time, like other disciplines, IS/KO has also used conceptual models to formalise specific domains of interest and make them suitable for computational implementation. Examples include the FRBR (IFLA, 1998) and Library Reference Model (LRM; Riva et al., 2017), the RiC-CM (International Council on Archives, 2023) model, the Bibliographic Framework Initiative (BIBFRAME) model (Library of Congress, n.d.), the CIDOC CRM model (International Council of Museums, n.d.), and the thesaurus conceptual model defined in ISO 25964 (Will, 2012).

3.2 Hjørland's Domain-Analysis Approach

Within the IS/KO literature, Hjørland is an author that stresses domains as sources of semantics. According to him, "semantic issues underlie all research questions within Library and Information Science (LIS, or, as hereafter, 1S) and, in particular, the subfield known as Knowledge Organization (KO)" (Hjørland, 2007, p. 367). This approach asserts that meaning arises from domains of human action and from the ways in which human groups communicate and agree on such meanings. This perspective mirrors how a systems modeller approaches a domain when designing an information system by interacting with the actors within the domain to identify its objects, their relationships, and the rules that govern them. This information then serves as input for the system modelling process.

Hjørland seeks to identify the sources of meaning underlying the terms that make up taxonomies, classification systems, thesauri, and other KOS—the core objects of IS/KO activity. This perspective broadens the scope of domain modelling to include the development of KOS. Through everyday discourse, such communities agree on the terms used to name objects, their properties, their relationships, and the procedures and rules involving those objects.

> The domain-analytic paradigm in information science (IS) states that the best way to understand information in IS is to study the knowledge-domains

> as thought or discourse communities, which are parts of society's division of labour. Knowledge organization, structure, co-operation patterns, language and communication forms, information systems, and relevance criteria are reflections of the objects of the work of these communities and of their role in society (Hjørland and Albrechtsen, 1995, p. 400).

From a methodological perspective, Hjørland argues that domain analysis is a key strategy for understanding how knowledge is organised and represented within specific communities and disciplines (Hjørland, 2002).

In a subsequent publication, the author notes that:

> Domains are basically constituted of three kinds of theories and concepts: (1) ontological theories and concepts about the objects of human activity; (2) epistemological theories and concepts about knowledge and the ways to obtain knowledge, implying methodological principles about the ways objects are investigated; and (3) sociological concepts about the groups of people concerned with the objects. There are complicated relations between these elements. Basic theories about those relationships are, for example, forms of philosophical realism and social constructivism (Hjørland and Hartel, 2003, p. 239).

The author delves further into issues related to modelling and representing domains in KOS, referring to the ontological, epistemological, and sociological dimensions of a domain as metatheories (Hjørland, 1998), and argues that these dimensions should be made explicit in a KOS.

3.3 Ranganathan's Facet Classification

Ranganathan, a pioneer of classification systems, distinguished three levels involved in a classification system: the idea level, the verbal level, and the notational level (Ranganathan, 1965, p. 4). This distinction is conceptually similar to database modelling, which involves the creation of conceptual, logical, and physical models as specified in the ANSI/X3/SPARC architecture (Brodie and Schmidt, 1982). Although Ranganathan did not use the terminology of conceptual modelling, these levels clearly anticipate the concept. The idea level is externalised in the verbal level, which conveys the meaning of a concept. In classification schemas, taxonomies, and thesauri, the verbal level may be serialised using a code rather than a linguistic term. This framework was further developed within IS/KO. Ranganathan also addressed the assignment of complex subjects to books and the articulation of simple subjects into classification notations (Ranganathan, 1967b). He was the first to recognize that a book may have more than one broad subject — typically the scientific discipline to which it belongs—and multiple facets within that subject. He proposed a notation system to code the position of a book on a library shelf that would integrate these different facets.

Proposed in the 20th century by Ranganathan and others, facet classification offers an alternative to the rigidity of enumerative bibliographic classification systems, in which a book is assigned to a single class based on its general subject. Such systems can be problematic when a book has more than one subject, 'point of view', or facet. For example, consider a book titled 'Control of virus diseases of the stem of rice plants in the winter of 1967 in Madras' (Ranganathan, 1967a, p. 409). In faceted classification, each component of a compound subject is treated as a facet when generating the notation used to locate and retrieve the book. As a result, faceted classification schemas function as information retrieval devices that retrieve entity representations based on their properties. These properties may be the multiple subjects of complex works, as suggested by Ranganathan, or product characteristics in contexts such as e-commerce platforms (Rosenfeld et al., 2015).

Ranganathan (1967b, p. 88) defined 'facet' as "a generic term used to denote any component—be it a basic subject or an isolate—of a compound subject, as well as its respective ranked forms, terms, and numbers". According to him, facets of compound subjects fall within five fundamental categories. Ranganathan (1967a, p. 404) explicitly notes that these categories are not intended as metaphysical categories.

> There are five and only five Fundamental Categories—viz., Time, Space, Energy, Matter, and Personality. These terms and the ideas denoted by them belong strictly to the context of classificatory discipline. They have nothing to do with their use in Metaphysics or Physics. In our context, their significance can be seen only in the statements about the facets of a subject—their separation and their sequence. This set of fundamental categories is, for brevity, denoted by the initionym PMEST (Ranganathan, 1967a, p. 404).

The subject of a book can be anything—any of the five Fundamental Categories, or any entity in reality—that refers to the fundamental categories originally proposed by Aristotle (Aristóteles, 2000). Other authors have also recognised the relationship between Ranganathan's five fundamental facets and Aristotle's fundamental categories (Aranalde, 2009).

The PMEST schema of fundamental facets, or categories, of a subject was further developed by the British

Classification Research Group (CRG) in the 1950s and 1960s. The CRG was a group of Library and Information Science researchers concerned with the classification and retrieval of books and scientific literature by subject (Vickery, 1980). The CRG postulated the following general categories: things/entities, kinds, parts, properties, materials, processes, operations, patients, products, by-products, agents, space, and time (Classification Research Group, 1958).

Ranganathan also made a significant contribution to the modelling of the final classification schema. In his 'LIST OF PRINCIPLES' (Ranganathan, 1967b, p. 183), he set out well-founded principles for ordering entries in a list of indexing terms. These principles consider the ontological nature of the terms that make up the list, such as the 'Canon for Helpful Sequence', 'Principle of Later-in-Time', the 'Principle of Later-in-Evolution', and the 'Principle of Complexity', etc.

3.4 Dahlberg's Concept Theory Oriented to Referent as a Key Contribution to Conceptual Modelling

How does a modeller approach the task of modelling a domain? How can one identify the entities within a domain? Which are objects, which are their properties and relations, which are agents, which are processes, and which are rules? We live in an ever-changing world, and ontology is the discipline that seeks to answer the question of what exists. Answering such a question implies classifying something as a species of a genus and defining the class or universal to which it belongs. Even when proposing competency questions (Alharbi et al., 2024) or selecting a foundational ontology (Guizzardi et al., 2022)—both increasingly fundamental steps in ontology engineering—a modeller must first familiarize themselves with the domain to be modelled, identifying entities as classes, their attributes, and the relationships between them. But how does one begin this process? How can a person acquire the minimum knowledge required to formulate meaningful competency questions? What should be the focus? In reality, domains are essentially dynamic; classifying or defining something requires observation, analysis of domain dynamics, and attention to the processes in which entities are involved.

Dahlberg was a German documentalist, founder of the International Classification Journal (now Knowledge Organization Journal), and of ISKO, the International Society for Knowledge Organization. Dahlberg's (1992) Analytical Concept Theory, oriented to the referent, provides a comprehensive framework for addressing these questions. The formulation of properties, defined as 'true statements/predications about this item' (Dahlberg, 1977, p. 3), is a knowledge elicitation process that she proposed as early as the 1970s, at a time when knowledge elicitation techniques were not yet part of conceptual modelling methodologies (Shadbolt et al., 2015). Such 'predications' provide a solid first step in exploring, formalising, and structuring a domain.

Dahlberg begins her argument by discussing the emergence of scientific knowledge from a cognitive perspective. One of her key claims in response to the question "How does one acquire objective knowledge?" is that "it all starts by relating thoughts to the actually existing objects" (Dahlberg, 1977, p. 11). This position draws on the thinking of Gerard Vollmer (2004), a German physicist and philosopher whose work Dahlberg refers to as 'hypothetical realism'. Vollmer developed an evolutionary theory of knowledge and coined the term 'evolutionary epistemology'.

Dahlberg contrasts 'hypothetical realism' with idealistic approaches based on Kant's a priori forms of perception—space and time—and categories. Instead, this perspective emphasizes observing reality, testing hypotheses to explain or recognize it, and intersubjectively validating them through scientific practice. According to Vollmer (2004, p. 34), as cited in:

> Anything we claim to know scientifically can only be based on hypotheses and testing. His main theses are: "every recognition of reality is of a hypothetical nature, and there is a world which is independent of our consciousness, which is structured and which is self-contained. This world is partly recognizable and understandable by perception, thinking and intersubjective science".

Remarkably, this concept is strikingly similar to Peirce's (1994, CP 2.96, CP 2.99) notion of abductive reasoning.

Although not explicitly mentioned, Peirce's semiotic triangle inspired Dahlberg's concept triangle (Friedman and Thellefsen, 2011). This triadic relationship was incorporated into Dahlberg's Concept Theory. The constituent elements of a classification system are classes, which are expressed linguistically by terms, each of which delimits, for example, a scientific discipline. A term referring to a class, or type of object, conveys its linguistic meaning. Such a triadic relation—between an object, a sign that represents it, and the meaning conveyed, even in the absence of the object and within some context, was established by Peirce's semiotics: "A sign, or representamen, is something which stands to somebody for something in some respect or capacity" (Peirce, 1994, CP 2.228, p. 362). In this formulation, something—an object—is referenced by another thing (a sign), producing a meaning for someone, even in the absence of the object itself. Peirce's reference to context ("in some respect or capacity") is particularly noteworthy.

Dahlberg developed her concept triangle based on this semiotic triangle notion of perception and meaning-making. In her model, one vertex represents an item of reference—the object or thing under consideration, whether physical or conceptual. She replaced the vertex representing the meaning conveyed by the concept with a linguistic term that synthesises the agreed-upon meaning of the item of reference among the actors within a domain. Dahlberg's key contribution lies in her claim that the meaning of a term is generated from a synthesis of true predications about the item of reference that have been agreed upon by human agents within a given domain. She argues that 'statements about such an item result in definitions; that is, one refers to something known in a statement and adds to it what is to be stated in addition'. In such cases, a 'general concept' is 'involved.'

Each predication creates a knowledge unit that explicitly states the properties, or 'characteristics', of a concept (Dahlberg, 1977, p. 15). Dahlberg classifies these characteristics as either necessary or essential—subdivided into essence-constituting and essence-consecutive (the latter following from the former)—or accidental, subdivided into accidental-general and accidental-individualising.

Such true predications form the third vertex of the concept triangle. The collection of these predications constitutes the analytic phase of Dahlberg's theory, during which the characteristics of a thing or phenomenon are made explicit. This is followed by the synthetic phase, in which these characteristics are synthesised into a linguistic term—the concept—that conveys the meaning of the phenomenon. These terms become the units of KOS agreed upon within a community of agents. They represent 'hypotheses' about how reality operates within specific shared domains and are used to name laws, rules, processes, entities, their components, and their functions. It is noteworthy that these methodological aspects of Dahlberg's concept analysis, through true predications and their synthesis into a term agreed upon by a community of practice, bear strong analogies to ontology development methodologies such as Methontology (Gómez-Pérez et al., 2004, p. 133). Methontology proposes the use of structured forms to capture concepts and relationships within a domain, although it leaves open the question of how such concepts are initially obtained. A similar gap appears in several other methodologies. Dahlberg's Concept Theory can shed light on these issues. Indeed, a growing number of studies relate Concept Theory to conceptual modelling (Campos and Gomes, 2014; Maculan and Mesquita, 2023).

Dahlberg's Concept Theory is not based on the idealistic ontological primacy of concepts as entities; rather, it is rooted in a triadic relationship between the objects of reality, the terms that represent them, and the true propositions about such objects that are agreed upon by agents within a given field. This approach underscores Dahlberg's commitment to a realistic and objective perspective, treating objects of reality as the ultimate source of knowledge.

Dahlberg also proposes a typology of conceptual relations, classifying them as formal-categorial, material-paradigmatic, and functional/syntagmatic. Material-paradigmatic relations connect concepts to foundational categories, and it is clear that Dahlberg's approach is indebted to Aristotle. According to the author, 'Aristotle distinguished the following 1 + 9 forms of categories: Substance = Objects; Quality, Quantity, Relation = Properties; Activity, Passivity = Operations; Having Space, Time, Position = Dimensions' (Dahlberg, 2008, p. 163). Dahlberg presents another formulation of material-paradigmatic relations (Dahlberg, 2008, p. 172) as follows: '(1) Entities: Abstract entities, concrete entities and principles; (2) Properties: Quantity, Quality, Relation (in the sense of comparison); (3) Activities: Operation (active); Process (procedure); State (passive, zero-activity); (4) Dimensions: Time, Space, Position'. She further proposes that the category of a concept can be established through recursive predication, for example: "A weekly newspaper is a newspaper'. A newspaper is a document that appears periodically. A periodically appearing document is a document. And so on.'

She also proposes classifications of material-paradigmatic relations, subdividing them into hierarchical/specification, genus-species, partitive, and opposition relations, with further refinements within each category.

When analysing functional/syntagmatic relations, Dahlberg argues that while formal-categorial and material-paradigmatic relations offer a static view of a concept, functional/syntagmatic relations represent the processes in which a concept is involved. These relations are expressed by verbs or verb derivatives. Analysing the 'semantic valence' of a verb can reveal other entities involved in the functional/syntagmatic relationship, making this a useful methodological approach for conceptual modelling (Dahlberg, 1977, p. 23). The notion of 'semantic valence' was proposed by the linguist Charles Fillmore (1967) and includes roles such as Agent, Instrument, Dative, and Locative. These roles represent the underlying semantic functions of noun phrases associated with a verb and are widely used in linguistic ontologies such as WordNet and in natural language processing.

Dahlberg proposed a remarkable double articulation of a concept within a classification system: first, through a top-level category of formal-categorical relations, and second, through the level of existence to which a concept (and its object) belongs. The Theory of Levels of Existence is rooted in Aristotle's hierarchy of beings, distinguishing between dead and living entities, such as plants, animals, and humans. This idea was further developed by 20th-century philosophers Feibleman (1954) and Nicolai (1953). According to the theory, reality is composed of different levels, each resting on lower levels but also exhibiting new, emergent properties that do not exist at those lower levels. These properties arise as qualitative changes at higher levels. A level can be identified by novel phenomena that appear within it and do not exist below it. Higher levels depend on lower ones; they cannot exist without lower levels.

The main levels commonly acknowledged by different authors include matter, life, mind, and society. Gnoli (2008) presents a table comparing the various proposals.

In her proposal for the Information Coding Classification (ICC), a classification scheme for scientific disciplines, Dahlberg applied this double articulation. She positioned each scientific area according to both the level of existence of the phenomena it addresses and its formal categorical relation. The ICC is a matrix called the Systematifier, in which each subarea occupies a cell. This matrix has three main levels, each subdivided into nine sublevels of existence (Dahlberg, 1982). The first level includes: (1) Form and Structure; (2) Matter and Energy; (3) Cosmos and Geography. The second level concerns: Living Beings: (4) Biological; (5) Human; (6) Sociological. The third level covers Products of Man (Artefacts): (7) Economic; (8) Science and Information; and (9) Culture.

These levels are divided into nine categories, or 'nine general form categories for the subdivision of object areas', as follows:

> "These helped me to develop a series of nine general form categories for the subdivision of the object areas into aspects on the one hand and as a general subdivider called "Systematifier" for the subdivision of each subject or knowledge field on the other hand. 1. Theories, principles, and general questions 2. Specific objects of a field and their components, kinds, and properties 3 Specific operations in a field and their kinds and properties 4–6. Specific aspects/properties of a field or persons (under 5), or institutions (under 6) 7. Influences from other fields on the field in question, also its technology 8. Application of methods and operations of a field in other fields 9. Synthesis and distribution of the knowledge of a field." (Dahlberg, 2008, p. 163).

Dahlberg's text provides many examples demonstrating the dual nature of a scientific field, in terms of both its level of existence and the most abstract categories of its objects. In the Systematifier, she formalized this double ontological articulation. For instance, informatics/computer science is categorised as Level 8—Science and Information Area. Its general form category, or facet, is: "3 Specific operations in a field and their kinds and properties." As Dahlberg notes, 'The subject group 83 Informatics/Computer Science supplies hardware and software to handle scientific and other kinds of information; the forms and activities are summarised under 84 General Information, with fields such as…' (Dahlberg, 2008, p. 170).

Another complementary application of Dahlberg's Concept Theory is the construction of definitions (Dahlberg, 1982). Definitions are a type of 'true statement/predication' about the item of reference (Dahlberg, 1977, p. 13). The author distinguishes three types of definition: generic, partitive, and functional. Definitions are the extension of a class. Examples include:

- GENERIC DEFINITION - specifies the class to which an object belongs, plus its specific difference: A political party is a group of people who work to promote a political program.

- PARTITIVE DEFINITION - specifies the parts that make up a whole: The human body df head, trunk and limbs.

- FUNCTIONAL DEFINITION - specifies an object within a function or process, including relevant roles: A Phillips screwdriver is a tool with a thin, cone-shaped tip, used to loosen cross-head screws.

4. Discussion

CS develops both practical/methodological as well as significant theoretical contributions to conceptual modelling (Bork et al., 2019; Chen, 1976; Mylopoulos, 1992; Thalheim, 2018) and ontological foundations of conceptual modelling (Guizzardi, 2005; Guizzardi et al., 2015). In turn, interest in conceptual modelling emerged in the IS/KOS literature alongside the rise of ontologies as KOS since the 1990s.

One of the earliest references to conceptual modelling in the KOS literature is Soergel (1995), who proposed a data model for a thesaurus database. Explicit mentions of conceptual modelling in the IS/KOS literature are more recent (Coyle, 2015) and can be seen as a direct result of the practical use of conceptual models in IS/KO, such as FRBR, CIDOC CRM, and the ISO 25964 Data Model. Ontology development has emerged as a key area of convergence for CS and IS/KO.

A fundamental aspect of representation and modelling practices in IS/KO is that they were conceived to address the problem of locating books in a library. This work is specialized into descriptive representation (cataloguing) and thematic representation (indexing), since the historical objects of interest in IS/KO are documents, i.e., semiotic artefacts with subjects as attributes.

Frequently, within the practice of IS/KO, access points *are not* attributes of the object being described, but contextual and cultural properties assigned to the object's catalog record by information professionals to facilitate user access and retrieval. They are generally called facets, a concept coined by the librarian pioneer S. R. Ranganathan.

While CS has long used conceptual modelling as a necessary phase of systems development—aimed at planning information systems and enabling validation by future users—the aim of IS/KO in developing KOS as domain models is to provide finding aids for accessing the document collections. To obtain better finding tools, IS/KO has made extensive use of theories, methodologies, and best practices such as Concept Theory, Integrative Levels of Existence schemes, facet analysis, and higher-level category schemes—with notable contributions from theorists such as Hjørland, Ranganathan, and Dahlberg. Scholars in both CS and IS/KO emphasize the domain as a privileged source of information for conceptual modelling. In particular, Ranganathan stresses facets as specific views of entities within a domain; Hjørland stresses domains as sources of semantics and meaning; and Dahlberg stresses the capture of meaning through true and agreed-upon propositions about the entities within a domain.

Ever since Ranganathan proposed the concept of facet, it has proven to be highly fertile. Soergel (1985, p. 258) notes that "facets are aspects or viewpoints from which entities—such as food products or subjects (topics, themes) in an area such as education—can be analyzed". IS/KO has often used attributive indexing, intentionally assigning keywords to optimize retrieval, regardless of whether these attributes are inherent in the object itself. This attributive function is also stressed by Hjørland (2015, p. 124), who argues that the theories behind concepts must be considered when constructing KOS. Dahlberg (2008) similarly emphasizes the analysis of scientific disciplines through facets such as objects, methods, and theoretical bases in her proposal for the Information Coding Classification.

Within what is now called ontology alignment, Dahlberg also made remarkable contributions through her notion of "formal-categorial relations" (Dahlberg, 1977, 2008), which connect the object a concept represents to the categories under which it is subsumed. Dahlberg's "true statements/predications about this item" (Dahlberg, 1977, p. 13), which ground domain modelling, correspond to what Guizzardi and Guarino (2023, p. 1) call "true propositions" within a domain description.

When describing the functions of a KOS, Zeng and Mayr (2019, p. 210) claim: "KOS act as semantic road maps and make possible a common orientation by indexers and future users..." KOSs are, therefore, artifacts that materialize conceptual models of domains in the form of linguistic terms expressing entities and their relationships. When integrated with online IRS, KOSs act as guides for navigating through such conceptual models.

The increasing use of conceptual modelling within IS/KO represents a welcome influence from CS. Since the pioneering FRBR specification (IFLA, 1998), its use has grown within IS/KO, as information retrieval finding aids are increasingly required for resources beyond scientific disciplines—such as products on websites or symptoms in patient care systems (Giunchiglia et al., 2014)—creating new demands for IS/KO. To cope with such different domains, those author propose the DERA methodology for conceptual modelling, based in the principles of Facet Classification; "DERA accounts for entity classes (E), relations (R) and attributes (A) of the relevant entities in the domain (D) and models them as semantic facets" (Giunchiglia et al., 2014, p. 45).

IS/KO currently continues to make practical and theoretical contributions to conceptual modelling. Significant contributions are now being made to the construction of KOS on the Web. SKOS (2012) is the interoperability and representation standard for KOS that utilises semantic web technologies. Proposals for faceted classifications organised by integrative levels have inspired innovative approaches to representing KOS in semantic web formats, such as Resource Description Framework (RDF) and Simple Knowledge Organization System (SKOS; Gnoli and Tudhope, 2021).

The traditional view of conceptual modelling in CS is static, structural, even when modelling processes: 'Conceptual models are typically used to model static aspects of a domain, and consequently the represented universals are usually endurant.' (Guizzardi, 2005, p. 244). However, reality is dynamic, and the concepts and terms used to name entities and their properties within a domain evolve over time. A remarkable contribution is the proposal for studies on the ontogeny of concepts—the evolution of concepts and the linguistic terms that represent them over time (Tennis, 2015). The author refers to these as 'second-order studies', focusing on how KOSs can be used more effectively, how they can be kept updated over time, and how the literary accuracy of the terms in a classification scheme can be maintained. Such studies are essential for maintaining and updating functional classification schemes such as Gene Ontology (Gene Ontology Overview, 2026), Unified Medical Language System (UMLS) and MeSH. Furthermore, emerging research issues concerning the modelling of the dynamics of domains are how the evolution of KOSs concepts over time has can be used as evidence to identify scientific discoveries (Reis Malheiros and Marcondes, 2013), and the how the statistical modelling provided by Data Science (Shah, 2020) can enable the dynamics of a domain.

5. Conclusions

This article aimed to present and discuss the contributions of IS/KO to conceptual modelling and to compare these contributions with those of CS. Throughout the article, several contributions to conceptual modelling, from both CS and IS/KO, were presented, analyzed, and compared.

Conceptual modelling originated in CS as a methodological tool for planning databases and information systems. It has emerged as a key discipline for discovering, accessing, and "understanding domains of interest" (Vickery, 1997, p. 277), as well as for reusing the growing amount of digital data through KOS. Although conceptual modelling in CS and in IS/KO shows a growing convergence and interbreeding of methodologies, both disciplines maintain different foci, due to their distinct origins and pragmatic objectives.

Since the advent of Big Data, modelling, in its broadest sense, has become an increasingly important means of making sense of data. According to Hjørland (2018, p. 690), a datum—the unit of data—is a triple (e, a, v), where 'e' is an entity in a conceptual model, 'a' is an attribute of entity 'e', and 'v' is a value from the domain of attribute 'a'. Identifying the conceptual models implicit in the data—its entities, attributes, and relationships—is essential for assigning meaning to the data. In this context, modelling is akin to representation. Representing, including the assignment of access points, is essential for the finding and retrieval of data.

Classification has long been a key area of application for IS/KO. The previous quote from Smith (2006), which refers to the importance of classification for ontology, shows that this is an interface area between IS/KO, conceptual modelling, and ontological analysis. The search for semantics, meaning, accuracy, and correspondence to real-world objects when representing and modelling domains of human action is critical for developing information systems, computational ontologies, and KOS. This appears to be a common goal of both CS and IS/KO. In this context, Dahlberg's contribution emerges as especially important for domain modelling, as it provides methodological insights not found in other traditional methodologies originating from CS.

Beyond conceptual modelling, future research areas within this scope include the use of ontologies to assign meaning to data and the use of different points of view to represent data for retrieval purposes. Other areas include statistical models to identify insights in large data sets. Another key area of future research is metamodels and metamodelling. Metamodels carry the potential for meaning. In ontological analysis, metamodels and metaproperties refer to instances of classes (Guarino and Welty, 2000). In the context of Big Data, it is sensible to include statistical functions that refer to sets of instances as carriers of meaning, that is, as metamodels.

Nowadays, the development of KOS is, in practice, the development of automated, computational KOS. In this context, ontological analysis and conceptual modelling are essential skills for information professionals. Although conceptual modelling arose as an essential phase in the development of computer systems, IS/KO can contribute a great deal to this process in terms of theories, methodologies, best practices, and practical guidance. KOS in digital environments will be required both to faithfully represent domains formally and serve as finding aids for information retrieval. Such objectives are not contradictory. Recognising these different functions will bring the fields of computer science (CS) and IS/KO closer together.

Availability of Data and Materials

There is not any dataset associated to this research.

Author Contributions

CHM confirms sole responsibility for the conception and design of the study, data collection, analysis and interpretation, drafting and revising the manuscript, and approval of the final version. The author has read and approved the final manuscript and agrees to be accountable for all aspects of the work.

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Conflicts of Interest

The author declares no conflicts of interest. Carlos H. Marcondes is serving as one of the Editorial Board Members of this journal. The author declares that Carlos H. Marcondes had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Lin Wang.

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During the preparation of this work, the author used ChatGPT-3.5 in order to check spelling and grammar. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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