Toward an Information Systems Ontology

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Abstract. We introduce the Information Systems Ontology (ISO), a new ontology for the Information Systems (IS) discipline designed to enable automated knowledge synthesis and meta-analysis of research findings in IS. We constructed ISO in a methodical manner, following known best practices for ontology construction. We also conducted a series of ontology refinement steps in which we compared and extended ISO by extracting and examining both overlapping and missing key phrases from scientific articles and existing classification schemas. To evaluate ISO, we extracted author-defined keywords from more than 7,000 articles of the senior scholars' basket of journals and measured terminological coverage. In one experiment, we found that our ontology included 3.6 times more author-defined keywords than an established classification schema for IS. In the future, we plan to use ISO to automatically annotate important IS terms and concepts in IS articles to help synthesize and analyze knowledge in IS.

Keywords: Ontology · Taxonomy · Information systems research · Information systems · Knowledge synthesis · Meta-analysis

1 Introduction

A large world-wide community of scholars devotes time, energy and resources to building new knowledge of Information Systems (IS). But because the community stores and disseminates this information in unstructured free-text documents, it is difficult to systematically and comprehensively examine the body of new and existing knowledge in the IS field. For instance, faced with a corpus of leading journals in IS, researchers and practitioners would have to painstakingly analyze each document in the corpus to answer questions about which new machine learning methods have recently been adapted for IS research or which research methods the IS field has historically used to study IT service management.

Storing knowledge in unstructured documents also presents additional problems. Researchers only loosely familiar with a given topic area (e.g., *deep learning*), may not know the complex array of named entities and sub-entities in a document collection (e.g., *long short-term memory*). Moreover, when researchers, reviewers and editors are

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no longer able to keep track of past contributions, it becomes harder to integrate new findings into a growing body of knowledge.

One possible approach to tracking and synthesizing the growing unstructured IS literature is automatically analyzing keywords in scientific articles, using a taxonomy or ontology to group keywords in a hierarchical and semantically meaningful manner. However, the most recent keyword classification schema in IS [4] was updated in 1993 and consequently doesn't contain current topics and technologies, such as *design thinking*, *model-driven development*, *cryptocurrency,* or *MapReduce*.

Therefore, in this work we propose the Information Systems Ontology (ISO) which aims to cover the broad IS field by organizing its topics, technologies, methodologies, and theories. We designed ISO based on known best practices from Arp et al. [2], motivated by the possibility of supporting new views and tools for understanding, systematizing, and exploring IS. While developing ISO, we performed an extensive series of refinement steps where we added terminology from automatically extracted scientific key phrases and existing classification schemas. Through this process, we created a comprehensive IS ontology with more than 2,700 entities and 380,000 synonyms. An entity represents a concept such as *design science* that could have multiple synonyms such as *design science research* or *design science method*. To evaluate ISO, we identified the most frequently used author-defined keywords in IS articles in eight top journals in IS [1] and found that our ontology includes 3.6 more author-defined keywords than a well-established classification schema for IS [4]. In the future, we plan to use ISO to build multiple systems for reviewing literature, researching topics and integrating knowledge from the IS field.

2 Taxonomies and Ontologies in IS and CS

The academic community has proposed a number of taxonomies and ontologies, as shown in Table 1. In IS, the classification schema of Barki et al. [4, 5] may be the most well-known taxonomy. Although it established an ontological foundation for IS, it was released almost 30 years ago. More recently, Gregg et al., Nickerson et al. and Springer et al. [13, 23, 29] developed taxonomies for e-commerce, mobile applications, and digital platforms. But they focused on sub-areas of IS, not on the discipline as a whole. Fteimi and Lehner [11] proposed a classification schema to support an integrated overview of Knowledge Management publications.

In Computer Science (CS), the ACM Computing Classification System [33] was created manually and may be the most widely used classification schema. It contains about 2,000 categories and its most recent version was released in 2012. The latest version (3.3) of the Computer Science Ontology (CSO) [27] was released in 2020 and is an example of an ontology that is created automatically via an algorithm.

There are differences between IS-specific and CS-specific classification schemas. CS-specific schemas, for instance, tend to contain more technical terms than IS-specific schemas, such as *packet processing*, *routing problems*, *signal encoding* or *combinatorial algorithm*. However, there are many overlaps as well, for instance regarding technologies such as *deep learning*, conceptual methods such as *dynamic programming* or analysis methods such as *natural language processing*. Because of the many overlaps, we compared our ontology to the most recent classification schemas in both IS and CS, namely Barki et al., the CSO and the ACM Classification System, in Sect. 5 of this paper.

Table 1. Related classification schemas and ontologies

Name	Author	Year	Domain	Approach	Evaluation method
Keyword classification schema for IS	Barki et al. [4, 5]	1993	IS	Manual	User feedback
Taxonomy generation for text segments	Cuang and Chien [8]	2005	IS	Automatic	User feedback
Taxonomy for personal health systems	Beranek et al. [6]	2006	IS (Health System)	Manual	–
Taxonomy for complaints about EBay sellers	Gregg et al. [13]	2008	IS (E-commerce)	Manual	–
Taxonomy of mobile applications	Nickerson et al. [23]	2009	IS (Mobile applications)	Manual	Expert assessment
AcademIS	Triperina et al. [30]	2013	General	Manual	Case study
Scholarly ontology	Pertsas and Constantopo-ulos [25]	2017	General	Manual	User feedback & expert assessment
CSO	Salatino et al. [27]	2018	CS	Automatic	Automatic
SemSur	Fathalla et al. [10]	2018	General	Manual	Questionnaire & expert assessment
Taxonomy to gamify information systems	Schöbel et al. [28]	2018	IS (Gamification)	Manual	Case study
Knowledge management classification scheme	Fteimi and Lehner [11]	2018	Knowledge management	Manual	Expert assessment
Taxonomy in business analytics	Ko and Gillani [17]	2020	IS (BA)	Hybrid	Expert assessment
Taxonomy of digital platform pricing	Springer and Petrik [29]	2021	IS (Digital platform pricing)	Manual	Expert assessment

3 Ontology Development

We developed ISO using known best practices [2]. The development proceeded in a series of steps. We began by developing a top-level hierarchy and defining inclusion and exclusion criteria for entities and their synonyms in the ontology.

We use the word **entity** to refer to a term in our ontology, e.g., *artificial intelligence*. Each entity can have additional **synonyms**, e.g., *AI*. Entities can be added below other entities to create a hierarchy, resulting in different hierarchy **levels**. We use the term **candidate entity** or **candidate** to refer to terms that might be added to the ontology during refinement.

After that, we reviewed terminology from standard textbooks and IS articles in order to identify entity candidates. We also developed a program that used wild card patterns to identify additional entities in IS articles. Further refinement steps included the automated extraction of scientific key terminology from IS articles and a comparison with an existing classification schema in IS.

3.1 Development and Population of a Top-Level Structure

We followed a series of steps for designing a domain ontology, defined by Arp et al. [2]. In order to identify entities for the two top levels of the ontology, two authors with a combined experience of more than 20 years in IS analyzed IS-specific as well as general social science taxonomies, thesauri and ontologies [12, 18, 31] and standard textbooks [7, 14, 20–22, 24, 26, 32]. From these resources, the researchers created a list of entity candidates and considered each individual candidate for possible inclusion in the top-level structure. The researchers selected candidates which were abstract and closely related to IS, so that the ontology could answer how research is conducted in the IS discipline. For instance, we consider *data analysis method* to be an abstract entity and *multimodal sentiment analysis* to be a specific entity. For reasons of feasibility, we decided to limit the scope to IS-related terminology and excluded terms that represent business terminology without a close relation to IS, e.g. *marketing*, *management*. The resulting top-level structure consists of three entities on the first and fourteen entities on the second hierarchy level as illustrated in Fig. 1.

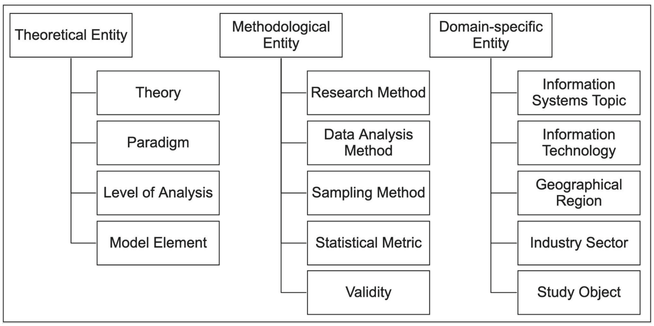

Fig. 1. Ontology top-level structure

3.2 Development and Population of Lower Hierarchy Levels

For the addition of entities into lower hierarchy levels of the ontology, we defined several inclusion and exclusion criteria as illustrated in Table 2.

Table 2. Inclusion and exclusion criteria

Criteria	Description
Inclusion	- the term must be abstract - the term must be used in many different papers - if the term is an acronym, it is only added if it is introduced with parentheses, i.e., *Information Systems (IS).* Otherwise, it is ambiguous
Exclusion	- terms that are construct names - terms that are measurement items (questions) from surveys - terms that represent business administration concepts, e.g. sales, marketing - terms found in diagrams and tables - terms that are ambiguous or unspecific, e.g. least squares, management system, value chain, business strategy, critical success, total number

To define and populate the ontological hierarchy, the same two researchers as in Sect. 3.1 performed several ideation sessions in order to collect and discuss terminology from standard textbooks. After that, they grouped and included entity candidates in an iterative process to further develop the hierarchy. Table 3 details which sources were used to determine entities for lower hierarchy levels.

3.3 Refinement with IS Articles

To refine the ontology, the researchers created a corpus of articles in IS. This corpus consisted of 7,304 scientific articles from the senior scholars' basket of journals, published between 1989 and September 2021. This *basket* of journals represents the top eight journals in IS [1]. The researchers manually analyzed a sample of this corpus consisting of roughly 150 articles for missing entities and potential synonyms. During enhancement, one researcher informally picked the relevant sections from a paper and added possible entity candidates to a list. In a second step, this list was compared with existing entities in the ontology and missing entities were added.

3.4 Refinement with Wild Card Patterns

In order to identify additional entity candidates, the researchers developed an automated procedure using wild card-patterns for analyzing text. These patterns used part-of-speech (POS) tags to identify common multi-word sequences or phrases in IS articles; researchers have long used POS tags to identify scientific terminology [15]. For example, to identify additional entity candidates related to the entity *theory*, we searched IS articles using the pattern "theory of $ADJ? $NOUN|PROPN +" to detect word sequences

Table 3. Top-level entities with examples and sources

Level 1 entity	Level 2 entity	Examples	Source
Theoretical entity	Theory	Information systems theory, social sciences theory, management theory, economic theory	[19, 22]
	Research paradigm	Realism, pragmatism, positivism	[7, 32]
	Level of analysis	Macro level, meso level, micro level	[32]
	Model element	Construct, variable	[7, 26]
Methodological entity	Research method	Conceptual methods, e.g., design science, simulation; Data collection methods, e.g., case study, experimental design	[14, 18, 24, 26]
	Data analysis method	Triangulation, synthesis, machine learning or descriptive statistics	[12, 21]
	Sampling method	Purposive sampling, critical case sampling, cross validation and bootstrap sampling	[32]
	Statistical metric	Goodness of fit, standard deviation, mean squared error	[12, 21, 32]
	Validity	Diagnostic validity, construct validity, design validity	[32]
Domain specific entity	Information systems topic	Knowledge management, business process management, gamification, information systems strategy	[20]
	Information systems technology	Internet technology, social media or mobile systems, semantic web, ubiquitous computing	[20]

(*continued*)

Table 3. (*continued*)

Level 1 entity	Level 2 entity	Examples	Source
	Geographic names	Europe, Western Europe, United Kingdom, England, London	[31]
	Economic sector	Manufacturing industry, chemical industry, pharmaceutical industry	[31]
	Study object	Company types or participants, e.g., startup, small and mid-size enterprise, individual participant, group participant, organizational participant	[31, 32]

starting with *theory of* followed by zero or one adjectives and one or more nouns or proper nouns (e.g., *Theory of organizational creativity)*. We developed multiple patterns to identify additional entity candidates. The researchers analyzed pattern matches in the corpus of IS papers (defined in Sect. 3.3) according to the inclusion and exclusion criteria.

3.5 Refinement with Extracted Scientific Key Terminology

We compared and refined our ontology with automatically extracted scientific key terminology from IS papers to test and improve the terminological coverage of our ontology. Therefore, we identified the most frequent scientific terms from articles in our corpus consisting of 7,304 scientific articles from the senior scholars' basket of journals, published between 1989 and 2021 and compared those terms against the entities in our ontology. If an extracted term was missing in the ontology, two researchers discussed the term as a potential entity candidate and decided whether to include it or not, based on the criteria in Table 2.

To extract terms, we used the combo basic term extraction algorithm [3] from PyATE, a term extraction library in Python [16]. This algorithm identified key terms from natural language text related to their frequency. Applying the algorithm to all full text articles in our corpus resulted in a list of 32,517 terms. We ranked the terms based on the number of articles where a term was among the top 10 extracted terms. The term *information systems* was for instance among the top 10 terms in 2,487 papers, followed by the term *information technology* in 1,371 papers.

We only reviewed terms that were among the top 10 terms in at least 10 articles. This resulted in a new list of 600 entity candidates where 384 of them were not included in our ontology. Two authors performed a review and discussed all of these 384 entity candidates: 123 entities were added to the ontology, 213 were excluded and 48 were regarded as subjects for possible future inclusion.

Terms starting with *information* or *data* are common in IS. Out of the 32,517 terms, we therefore reviewed another 1,199 entity candidates starting with such terms. 1,026 candidates didn't meet the inclusion criteria, 52 were marked for possible future inclusion and 121 entities were added to the ontology.

3.6 Refinement with IS Classification Schema

In 1988, MIS Quarterly published an IS classification schema by Barki et al. [5] that was updated by Barki et al. in 1993 [4]. The updated version contained around 1,300 keywords. We refined our ontology by comparing it to this updated classification schema.

We extracted the terminology from the classification schema of Barki et al. into a digital format and automatically searched for matching entities in our ontology. Out of the 1,300 terms, 228 were already included which also means that the classification schema of Barki et al. didn't contain 2,524 entities (382,873 including synonyms) that were contained in our ontology. For instance, Barki et al. didn't include terms such as *knowledge management*, *open source*, *human centered design* or *usability*.

For terms in the classification schema of Barki et al. that were not in our ontology, one senior and one junior researcher independently performed a review on whether those should be added. The inter-annotator agreement [9] for these 1,072 terms resulted in a Cohen's Kappa value of 0.56 which is regarded as moderate agreement. The kappa value may reflect the difference in research experience or ambiguity in some terms. The two researchers discussed all terms where the evaluation indicated disagreement (n = 231) and decided whether those should be added to the ontology. As a final result, the researchers added 336 entities and additional synonyms.

We analyzed a random sample of terms that were contained in the classification schema of Barki et al., but not in our ontology and found that most of these terms didn't meet our inclusion criteria. Table 4 provides an overview with examples.

Table 4. Terminology from Barki et al. that is not in ISO

Exclusion category	In Barki et al., not in ISO (n = 736)
Unspecificity	Data structure, graphic design, information, measurement
Ambiguity	Accessibility, homes, output, piracy
Different focus	Accounting, human resources, management level

As demonstrated by Table 7, the differences between ISO and the classification schema of Barki et al. seem to stem from the lack of specificity, the ambiguity or simply terms from Barki et al. that were not sufficiently focused on IS to meet the inclusion criteria for ISO.

4 The Information Systems Ontology

In total, ISO contains a total of 2,752 entities and 383,101 synonyms. The tree is organized with three top-level entities, named methodological entity, theoretical entity and domain-specific entity. These three entities provide a logical grouping of fourteen core entities on the second hierarchy level that we believe are central to describe scholarly papers in IS. Table 5 provides an overview of these entities including three metrics to get an impression of the ontology contents: *count of levels* stands for the maximum number of hierarchical levels below a top-level entity, *count of entities* stands for the total count of entities below a top-level entity and *count of synonyms* stands for the count of included synonyms (each entity can have many different synonyms).

We enhanced the list of entities in our ontology with various synonym-, prefix- or suffix-lists (where prefix and suffix mean the first or the last word in a multi-term word) that are directly encoded within the ontology. For instance, for the entities *design science methods* and *case study methods*, we apply the same synonym-list to automatically generate additional terms by exchanging the last word. This results in terms such as *design science technique* or *design science methodology* and *case study technique* or *case study methodology*.

Table 5. Ontology overview

Ontology top-level entities	Count of levels	Count of entities	Count of synonyms
Theoretical entity	**10**	**321**	**2,758**
Level of analysis	7	14	44
Model	6	35	1,278
Research paradigm	6	14	326
Theory	9	258	1,110
Methodological entity	**11**	**841**	**85,715**
Research method	9	290	63,020
Data analysis method	10	411	3,779
Validity	6	27	16,874
Sampling	8	28	172
Statistical metric	7	85	1,870
Domain specific entity	**11**	**1,590**	**294,628**
Information systems topic	10	392	19,031
Information systems technology	9	488	36,124
Study object	8	24	235,750
Economic sector	10	338	2,849
Geographical names	10	348	874
		2,752	**383,101**

5 Evaluation and Discussion

In IS journals, authors often provide keywords that help define the contents of an article. The assumption is that author-defined keywords are relevant to IS. To evaluate our ontology, we extracted all author-defined keywords from the articles in our corpus (defined in Sect. 3.3), resulting in a list of 13,987 unique terms. In order to evaluate how well our ontology is suited to detect relevant IS terminology, we counted how many of the extracted author-defined keywords are contained as entities in ISO. For this search, we specified that an author-defined keyword was included in our ontology, if the exact string matched an entity or one of its synonyms. We performed the same search for keyword-matches in the classification schema of Barki et al. [4], the CSO [27] and the ACM classification schema [33].

We performed two tests: first, we counted matches among all extracted keywords and second, we examined the 1,000 most frequently used keywords. Frequency is defined as the number of papers which contain a keyword at least once. Table 6 shows the results.

Table 6. Comparison with author-defined keywords

	Matches (all 13,987 keywords)		Matches (top 1,000 keywords)	
Ontology	#	%	#	%
ISO	1,830	13.1%	456	45.6%
Barki et al.	384	2.7%	129	12.9%
CSO	726	5.2%	170	17.0%
ACM	239	1.7%	75	7.5%

ISO includes 4.8 times more author-defined keywords than Barki et al. (i.e. 1,830/384), 2.5 times more than CSO (i.e. 1,830/726) and 7.7 times more than ACM (i.e. 1,830/239) for all keywords. ISO also includes 3.6 times more author-defined keywords among the top 1,000 most frequent keywords in IS articles than Barki et al. (i.e. 456/129), 2.7 times more than CSO (i.e. 456/170) and 6.1 times more than ACM (i.e. 456/75). These results suggest that ISO may be more appropriate for automatic tagging of IS articles than either alternative ontology or classification schema.

To gain further insight, we sampled keywords that were not captured by our ontology and found that most of these keywords didn't meet our inclusion criteria. Table 7 provides an overview with examples.

We developed ISO as an extensive ontology for the IS discipline aiming to automatically identify entities in scientific articles. ISO includes more relevant terminology than current classification schemas for the task of keyword detection in IS articles and covered 45.6% of the top 1,000 most used keywords.

During development, we focused on integrating as much appropriate terminology as possible and evaluated ISO based on its coverage of domain specific terminology. As our aim is to develop ISO as a keyword-detection tool, we focused on coverage as the main indicator for performance in this article.

Table 7. Examples of unspecific and ambiguous keywords

Exclusion criteria	In author-defined keywords, not in ISO
Unspecificity	Adoption, performance, culture, motivation, satisfaction, escalation, addiction
Ambiguity	Ethics, information, decision making, autonomy, success, web

In the future, more refinement will be necessary to increase the terminological coverage. We further plan to integrate the socio-technical perspective by adding more general business terminology. Ideally, a semi-automated approach can be developed for this task, similar to the approach of CSO where the ontology is automatically generated through the use of an algorithm. In addition to evaluating the coverage, an evaluation of the hierarchical structure of ISO through expert interviews could be a future refinement step.

6 Conclusion

This work introduces the Information Systems Ontology (ISO), a new hierarchical schema for IS research. ISO is motivated by a need to systematize and organize an ever-growing body of IS knowledge stored in unstructured documents. As described throughout this work, we developed ISO because we found that existing scientific classification schemas were either poorly suited to IS or did not cover the many important technological and methodological developments introduced to the IS field in recent decades. To create ISO, we followed known best practices for ontology development and performed a series of extensive ontology refinement steps to improve our schema's coverage of concepts in IS. In our final evaluation, we found that ISO included 3.6 times more author-defined keywords than the established ontology for IS. In the future, we plan to use ISO to identify similarities and relationships among IS articles and to support knowledge synthesis and meta-analysis in the IS field.

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