Empirical Methods for Knowledge Evolution across Knowledge Organization Systems†

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Abstract: Knowledge organization systems, including classifications, can be evaluated and explained by reference to what is called concept theory, attributing to concepts atomic status as basic elements. There are two ways to test knowledge organization systems; both are means of measuring the efficacy of concept theory in specific situations. These are: 1) analyze how well a system represents its warranted concepts; and, 2) analyze how well individual knowledge organization systems are populated with classified target objects. This paper is an attempt to bring together examples from ongoing research to demonstrate the use of empirical approaches to understanding the evolution of knowledge across time as it is represented in knowledge organization systems. The potential for using knowledge organization as a roadmap for the world of knowledge is revealed in the capability of knowledge organization systems to serve as roadmaps and data-mining tools for the knowledge landscape.

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1.0 KOS = Concepts

Knowledge organization systems (KOSs), including classifications, can be evaluated and explained by reference to what is called concept theory. In other words, knowledge expresses concepts, which are represented by terms. Knowledge elements represent predicates and referents of specific knowledge units. Knowledge units represent the synthesis of concept characteristics. Classes are large knowledge units that represent groupings of concepts according to prescribed characteristics, often as represented in texts (Dahlberg 2006 and 1978; Hjørland 2009). The concepts, their representations, and their groupings as represented in texts or other contextual environments (which we call domains) are derived according to a system known as warrant (see Beghtol 2010). Warrant is the justification for using a specific term to represent a particular concept.

Taken together, the elements just outlined constitute the essential aspects of any KOS, and therefore are the testable or measurable entities for the domain of knowledge organization (KO). We can extract sets of terms and define the concepts they represent. We can analyze the effect of one knowledge element on another in the formation of a knowledge unit. We can gather similar knowledge units and describe the synthesis of concept characteristics that constitute them. And we can study the means by which specific terms come to be used in a particular domain—their warrant—as well as the work done by the domain and the manner in which it affects the knowledge corpus in that domain and its evolution across time.

There are two ways to test KOSs and they are both means of measuring the efficacy of concept theory in a specific situation. These are:

1) Analyze how well a KOS represents its warranted concepts both individually and in contextual groupings; and,
2) Analyze how well individual classes, divisions and subdivisions of a KOS are populated by target objects.

In the first case, we seek to match the structure of a KOS with the knowledge base of a domain.

Many approaches from domain analysis (Hjørland 2002; Smiraglia 2015a) to subject ontogeny (Tennis 2006, 2007) have been used for the first test. Most domain analytical studies represent snapshots of a domain's ontology at a particular moment in time. Tennis' ontogenetic approach has successfully demonstrated the scope of change in the treatment of particular knowledge units across time in major bibliographic classifications.

Few studies have addressed the second test. A new research stream (Salah et al. 2012; Scharnhorst and Smiraglia 2012; Smiraglia et al. 2013; Smiraglia 2013a and 2014) developed using empirical methods to analyze the mapping over time of the Universal Decimal Classification. Apart from these studies, a major lacuna in KO is the lack of sufficient focus on the parallel evolution of knowledge and its representation in KOSs over time.

Of course, wide variation exists in approaches to research on KOSs, ranging from epistemological approaches to depth of analysis. For example, rather a lot of research in KO utilizes tools such as discourse analysis or critical theory to increase understanding of the contexts and uses of KOSs (Olson 2001b; Furner 2007; Martínez-Ávila and Fox 2015; Fox 2015). In a series of domain analytical studies of KO itself (Smiraglia 2013b), I have demonstrated the dichotomous role of empirical and non-empirical epistemic stances in KO and suggested that they constitute a rather useful form of constructive tension in the domain. Both approaches are necessary and useful, because it is as important to understand the sociological aspects of knowledge evolution and use in a domain as it is to extract a domain's knowledge base accurately and represent its concepts systematically.

In this paper, I will attempt to bring together examples from ongoing research to demonstrate the use of empirical approaches to understanding the evolution of knowledge across time as it is represented in KOSs.

2.0 The first test: Domain analysis

Domain analysis in KO is the set of research methods used to isolate and extract the knowledge base from a particular knowledge environment. After approximately two decades of research, a more or less stable group of empirical techniques has coalesced in KO and these are described several places (most recently in Smiraglia 2015). The various techniques range from methods for recording a specified knowledge base, through ethnographic approaches of the work of a specific group, quantitative analyses of texts and scholarly trace evidence such as citations and links, and on to outright historical analysis and the aforementioned approach to discourse analysis. All of these methods may be regarded as empirical, because all of them focus on the actual knowledge held, created and used in a particular, specified environment. Even discourse analysis in this regard is considered empirical. Obviously not all of the methods are quantitative, but a good mix of qualitative and mixed methods approaches also have been demonstrated in the literature of domain analysis in KO.

A key first step in any such study is operationalization of the domain for analysis. For two decades, as domain analysis was being established as a common research method in KO but also evolving in the science of information, scholars defined domains operationally in ways specific to each individual study. In 2012, I gathered all of the studies in KO together in order to analyze their epistemological foundations, as well as to comprehend the ways in which they had operationalized the notion of a "domain." In 2012 (114), I published an operational definition derived from this body of research. That definition included the following points:

– An ontological base that reveals an underlying teleology

  Typically a domain is a group involved in some discourse or other productive activity. However, it is not necessary for a group to be involved, a domain can be defined as the knowledge base of a particular scholar, or a particular concept, and so on. However, in every case, a domain will share a common goal that is implicit or explicit or both in its knowledge base;
– A set of common hypotheses

  If there is a theoretical paradigm in operation, it will dictate the hypotheses used in the domain for testing theoretical parameters. In non-scholarly domains, we can consider a parallel consideration to apply to means employed by the group to contribute to the evolution of its common goal;
– An epistemological consensus on methodological approaches

  Most domains that embrace a single theoretical paradigm (or a consistent set of such paradigms) will share methodological approaches rooted in different epistemological points of view; and,
– Social semantics

At the simplest level, this simply means that the group should be visibly in conversation utilizing its common ontology. At higher levels of complexity, it means that there should be records of communication and exchange of ideas; in scholarly domains, citation, intercitation and co-citation will be evidence of social semantics.

In the end, a domain in KO is the set of boundaries we place around the analysis, extraction and manipulation of a knowledge base. It can be a whole science, it can be a discourse community, it can be a working group in a particular place and it can be a single scholar for whom the intellectual unity is her own scholarship (Smiraglia and Beak 2015). To paraphrase the definition above, what matters is that a domain have an ontological base, an underlying teleology, an epistemic stance and reveals evidence of social semantics.

In recent analyses, I have described the approximately 100 publications that seem to report domain analytical research that was a result of the Hjørland 2002 catalyst (Smiraglia 2015a and b). Thirty domains have been studied once apiece, ranging literally from Accelerator driven systems to Yogic science. Eight domains were studied twice, including cooking, astronomy and tripsanomatides. Only two domains have been studied more than once—music and knowledge organization. There have been four domain analytical studies of the vastness of the domain of music; there have been twenty-two studies of our own domain. It is critical for empirical research, that analyses of the evolution of knowledge in a domain accompany domain analytical studies of that domain. There is much work to do.

3.0 Empirical "Ontogeny"

Ontogeny is a term used mostly in biology to describe the evolution of an organism. According to the *OED Online,* ontogeny combines the Greek root "onto," meaning being, with the suffix "geny," meaning evolution. Ontogeny literally means the evolution of an entity or phenomenon. In information and knowledge organization, the word has been introduced by Tennis (e.g. 2006) in the term "subject ontogeny," meaning the evolution of specific concepts, particularly as their evolution is visible in KOSs. The study of subject ontogeny is important and represents a major lacuna in KO because of the naive assumption that a "classification"—such as the famous bibliographic monolith *Dewey Decimal Classification* (*DDC*)—is somehow perfect in any moment for all time. Yet, as we are only too keenly aware, things change and sometimes fall apart (Achebe 1994). Sometimes things actually evolve. More often, time refuses to stand still and while specific players remain stable, the culture and environment around them changes. How, then, can a "universal" classification be "stable" if all of the concepts in it are subject to change? Thus Tennis' research stream forces the KO community to begin to think twice about the efficacy of mutually exclusive categories, of hierarchical arrangements that mirror Western culture and of concepts that never change. Tennis shows convincingly how "eugenics" evolves over a century from a biological term to a term used politically to control racial politics and even to justify genocide (there is that term "geno" again—here it means ridding oneself of evolution), to today's use as a botanical term describing evolution of specific special mutations. Yet in the *DDC*, Tennis shows, works classified under the term with all of these meanings are mixed in some collections, how in other collections *DDC* was not followed as it changed, and from his analysis an entire cultural history of one concept emerges from behavior related to classification. We should be reminded that, as in domain analysis, in ontogeny only one term has been studied. Much ground remains to be covered.

Tennis' study is essentially narrative analysis based empirically on assignment of classification numbers as he can find them in the OCLC WorldCat. One potential area for growth in the study of subject ontogeny comes from Olson's (2010) use of Hegelian philosophy as a filter for Western bibliographical classification practices. This is, of course, the notion of a progression of knowledge through three stages: being, essence, and notion (or idea) (25). Is it possible that the evolution Tennis documents is in fact evidence of such a progression? More analysis will be required to answer such a question, but the KO community definitely should begin to analyze major bibliographic classification ontogeny through such a lens.

What other empirical evidence is there of subject ontogeny? The answer emerges from a research stream from the Royal Netherlands Academy of the Arts and Sciences (Koninklijke Nederlandse Akademie van Wetenschappen or KNAW), where successive teams in the Virtual Knowledge Studio and the eHumanities Group have matched study of the evolution of knowledge (ontogeny) in Wikipedia with the evolution of the representation of knowledge in the Universal Decimal Classification (UDC), the only bibliographic classification conceived for use as a deconstructive tool for knowledge identification (ontogeny) and sharing. This group has discovered the social narrative of the growth of disciplines across the twentieth century, as well as the evolution of the classification played against the political and social backdrop of the twentieth century (Salah et al. 2012; Smiraglia et al. 2013; and Scharnhorst and Smiraglia 2012).

The narrative begins when Belgian visionary and documentalist Paul Otlet desires to implement a universal classification of knowledge to rein in his universal bibliographic control projects. Otlet eventually decided to import the basic structure of Dewey's 1876 *Decimal Classification* devel-

oped for library browsing. After much deliberation, Otlet settled on a related decimal system first published in 1905 as what has become known as the Universal Decimal Classification (International Federation for Documentation 1905). Otlet's version evolved, much as languages do, from its source over time in divergent ways such that today's UDC and *DDC* numbers bear only vague resemblance and probably only in the first digit as class, and then not always. There is no need to rehearse the two classifications or their orders here. Rather, the point is that Otlet's UDC became the only worldwide multilingual, multicultural (if heavily influenced by Western colonial powers) knowledge classification. This last point is important: where *DDC* remains a classification of books for libraries, UDC always has been a classification of knowledge.

The Dutch project team has spent almost a decade compiling and analyzing the entirety of the UDC and has created the only database of the UDC in which it is possible to trace particular concepts through the classification through time. But most of the team's research has sought to narrate the evolution of knowledge across the landscape of the twentieth century as it is told through the literary warrant encapsulated in the UDC. The research itself is reported in the several papers cited. But in general, the arc of what the team has discovered is along the following lines.

First, there is no, one, Universal Decimal Classification. Unlike the *Dewey Decimal Classification*, each edition of which from the beginning has been published in toto in print, there is no single instantiation of the UDC. It never has been published as a whole since its debut in 1905. Early in its history its editorial board decided that different national users would have different needs, so editions were compiled in different languages with somewhat different contents. It also was decided that the whole classification was too large to be published in a single set of volumes, so every publication over time was limited in size. The end result is that there is no bibliographic history of editions of the UDC, as there is with the *DDC* (which is why we render *DDC* in italics as a monograph but do not do so for UDC). There is a master reference file, which contains the current UDC at all times, and which now is in electronic form and is universally accessible through web portals. But the KSL research team had to compile the UDC in reverse from paper records, from reports of "editions and changes" in the KO literature, and by digitizing the 1905 edition.

More interestingly, perhaps, is the arc of change across the twentieth century. The first edition had 400 distinct main class locations, by 2009 there were 68,551, a growth in granularity and specificity of more than 170%. The majority of this growth took place in mathematics, the natural sciences and the applied sciences, which accords with the general comprehension of the technological century. Philosophy and generalities remained essentially unchanged, but the former bibliography evolved into computer science and knowledge organization, and the former class 4 was vacated by moving linguistics into class 8, adjacent to literature.

Another of Otlet's innovations was to create flexibility by the use of synthesis, meaning allowing any two or more classes to be expressed together (e.g., politics and opera) through the use of a symbol designating such, usually the colon ":" but sometimes also the plus sign "+." What is called a phase relation (e.g., politics in opera) can be expressed by placing the phased class in parentheses following the primary class. Also, through the use of auxiliaries facets may be indicated. There are both common and special auxiliaries in the UDC. Common auxiliaries such as language, locus or ethnicity can be expressed alongside any other class symbol. Special auxiliaries may be used only as indicated with particular classes. As of the analysis in 2009, there were over 13,000 common auxiliaries and over 9,000 special auxiliaries available. In other words, dramatic growth in the use of auxiliaries over time has introduced an immense capability for specificity into the UDC. Most of the growth in special auxiliaries was in class 6, applied sciences, which was to be expected. But also, there was dramatic growth in class 2, religion, after 1998, indicating an editorial revision of the class that was accomplished by detailing subdivisions rather than by altering main classes.

In addition to analyzing the evolution of the UDC itself, this team has had the opportunity to evaluate the population of the UDC from several perspectives. That is, we have been able to quantitatively analyze how the actual UDC numbers have been applied over time in several venues. We received entire files of UDC numbers from the OCLC WorldCat, from the library of the Katholische Universiteit Leuven, from the National Library of Portugal, BND domínio público (a dataset of the Portuguese National Digital Library) and PORBASE (the union catalog of Portuguese libraries). Results have been surprising. Again, the details are in the several cited papers, but the narrative has the following arc. Most of the works with UDC numbers in the OCLC WorldCat, at Leuven, and in PORBASE were published post-1979, although the range stretches from the 17th century to the present. However, in the BND, the well-populated portion was dated from 1700 to the present; the BND ranged from 1875 to the present. The differences are apparent, but the reason for them is not clear. It is possibly a reflection of collection development, which could in turn reflect the larger discourse of academic society during shifting periods of upheaval and peace in Europe. It could be an artifact of the retrospective conversion of paper catalog records to digital form. We cannot know for certain without corroborating data on

collection development statistics from the several venues. As regards the most populated classes of the UDC: in Leuven it was 6 "applied sciences," 3 "social sciences" and 2 "religion;" in the WorldCat 3, 6 and 8 "language and literature." The BND had 7 "arts entertainment sport" and 9 "geography, history" at top. PORBASE and BNP mirrored the WorldCat with 3, 8 and 6. Again the differential most likely reflects the academic discourse influencing collection development in Belgium and Portugal, but it is curious that the major Portuguese sources mirror the WorldCat.

One final note on the observed use of the UDC, and this is the most famous string we uncovered in the WorldCat. It was described in detail in Smiraglia et al. (2013, 4-5). The string was:

394.4:[92(100+437):329(437).15(091)+327.32(100)]

The explanation goes like this:

- 394.4 is a main UDC number standing for "Public ceremonial, coronations"
  Colon ":" is a connecting symbol representing "simple relation"
- Square brackets are used for subgrouping. Everything within the [….] brackets is a unity. This unity starts with another main UDC class number 92, standing for "Biographical studies. Genealogy. Heraldry. Flags"
- The () parentheses when starting with a non-zero numeric character denote a common auxiliary number of place. (100+437) indicates "(100) All countries in general" and "(437) Czechoslovakia (1918-1992)"
- 329.15 is for "Political parties with a communist attitude"
- The auxiliary of place "(437) Czechoslovakia (1918-1992)" is intercalated between 329 and 15 to allow for collocation of all Czechoslovakian parties irrespective of their political orientation, and then ordered by a type—thus the entire number represents a topic "Communist party of Czechoslovakia" which is then further specified by a common auxiliary of form (091) denoting presentation in a historical form to express "the history of communist party of Czechoslovakia"
- Plus "+" is the common auxiliary for addition/coordination introducing the next UDC number combination in the string consisting of two parts: "327.32 International solidarity of the working class" and "(100) All countries in general"

In other words:

Public celebrations/ceremonies with significant biographical and historical elements, or even artifacts to do with celebrations (e.g. flags, banners) and which involve historical personalities (both Czechoslovakian and international) linked to the history of Czechoslovakian Communists Party and international movement of solidarity of the working class - in the world.

Such a book would probably have something to do with parades and celebrations of May 1 International Workers' Day or similar events in former Czechoslovakia.

3.1. Network analysis

Part of the research has been an attempt to uncover networks within the application of the UDC, and networks between the components of UDC strings and the bibliographic characteristics of the classified files. The Dutch team cited in the preceding section developed an approach to network analysis of the main classes, auxiliaries and associated classes in the existing UDC strings. A clear network was uncovered, and network visualizations appear in all of the papers cited. The promise of such analysis is the ability to predict co-occurrence of phenomena. That is, if we know a specific class is present, with enough replication we should be able to predict the probability that a certain auxiliary also will be present.

But we also can take this one step further by analyzing the probability that the presence of certain combinations of UDC entities—classes, auxiliaries, etc.—can be predictably associated with the presence of other bibliographic characteristics, such as form, genre, place of origin, date of origin and so forth. In three papers (Smiraglia 2013a, 2014 a and b), this was tested using Chi-squared tests of nominal level data. Precisely, in all three cases, random samples were drawn from the data files of UDC assigned strings from the OCLC WorldCat and Katholische Universiteit Leuven. Basic statistical tests of date of publication and UDC main class population were run and were found in all cases to match exactly the population distributions in the earlier papers, thus demonstrating the efficacy of the samples. Then, for each UDC string, the main classes and auxiliaries were decomposed and cross-tabulated with place and date of publication, publisher, edition, series, presence of ISBN, presence of bibliography and main subject heading or subject term assigned. IBM-SPSS was used to generate Chi-squared matrices.

There were strong associations between the presence of a name as subject and the use of an uncontrolled index term, the presence of a place name and the presence of a genre or form. However, although many place names occurred in the file, only three—Madrid, Prague and Barcelona—occurred often enough to generate statistically significant correlations. Publisher names were even more diverse with only one occurring often enough to generate statistically significant correlations. Place and publisher, in the analysis to date, are not sufficient alone to predict other bibliographic or conceptual characteristics. Topical subject

headings were weakly associated with the presence of names, places and genre terms. Eighty-four percent of the UDC numbers have no common auxiliary associated with them, indicating the usage is relatively rare in the dataset. However, all of the main classes appear following linking auxiliaries.

Thus, statistically-significant correlations occurred among most of the deconstructed components of the UDC numbers, meaning that if we know of the presence of one class we can predict the probability of its co-occurrence with another class. Similarly, statistically-significant correlations were discovered among bibliographic elements, meaning the presence of one (e.g., a series statement) can predict the presence of another (e.g., a bibliography). And, statistically-significant correlations were discovered between the elements of classification and the bibliographic elements. Thus, the presence of a particular main class and auxiliary might lead to prediction of the presence of a bibliography or series statement.

These associations revealed the presence of a network of predictable interactions among classified bibliographic entities and the components of the classification. We are accustomed to thinking of the role of classification as ending with description of the subject of a document. In fact, it turns out a specific classification profile can richly predict the presence of bibliographic characteristics. This means classification strings can be a valuable approach to data-mining in large bibliographic systems. As it happens, classification is an integral artifact of the environment it classifies, providing pointers to interlinking pathways among the characteristics of the documents as well as their conceptual representations.

4.0 Classification is more than a gathering of concepts

The point remains that knowledge organization systems, including classifications, are more valuable than their simple utility as conceptual gathering or disambiguating systems. In fact, the complexity of KOSs allows the potentiality of their use for data-mining in large bibliographic databases. The empirical research summarized in this paper demonstrate the power of continued empirical analysis of KOSs and their application. Olson (1996) awakened the knowledge organization community to the epistemic authority of major classification schemes and their lasting influence on social discourse. Olson (2001b) asked us to consider "sameness and difference" and the differential between them. What we have observed in the intervening decade and a half is that the differential provides powerful predictable capabilities.

The domain of knowledge organization, like the research here, seems nestled in an adolescent stage, unsure of its theoretical capability and yet beginning to comprehend its power. Olson (2001a) was one of the first to move beyond concept theory to remind us of the power of concept representation to shape lives, to move communities, to direct domains of discovery and to create roadmaps in the universe of knowledge. It is clear from the research reported here that ample methodological approaches have arisen within the paradigm of classification evolution to begin to contribute to theoretical understanding of this power. Like its sibling domain analysis (Smiraglia 2015a), classification evolution will require much replication and additional empirical evidentiary analysis to reach the level of predictability it promises. It must be accompanied by empirical replication of scheme change analysis along the lines suggested by Tennis (2007). It must be interwoven with social discourse analysis as suggested and demonstrated by Martínez-Ávila and Fox (2015). In combination, a research agenda including empirical analysis of the construction and evolution of KOSs from the past can inform the future of the knowledge organization domain and its applications, and provide a blueprint for navigation of the knowledge landscape. But the potential for using knowledge organization as a roadmap for the world of knowledge—that which is known—is the true promise of knowledge organization as a science.

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