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Domain Maps: Purposes, History, Parallels with Cartography, and Applications

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Abstract

This paper discusses the history of domain maps in the context of similar developments in the field of cartography. Drawing from its underlying definitions, this paper identifies the purposes of domain maps and discusses how they might specifically be applied in the field of education and as front-ends to digital libraries.

Keywords--- domain mapping, history, theory, cartography, digital libraries, education, future

1. Introduction

The field of domain mapping is mature enough to merit some perspective, history, context, and an examination of its parallels with other fields—particularly cartography. This paper presents a conceptual framework for viewing the history of domain mapping and examines its purposes and applications.

2. Definitions and Purpose

Domain mapping is for the most part a subfield of information visualization. Furthermore, the purposes of domain mapping, scientific visualization, and information visualization are generally the same. These purposes are revealed in each of their definitions.

Information visualization and scientific visualization are strongly related (in fact, some note that the distinctions between the two have begun to blur [34]. Thus, conceptualizations of the one field have helped to illuminate the other. Scholars point to a 1987 coining of visualization in the sense used by this community [12,9,21]. This was in a report funded by the National Science Foundation (USA) entitled: *Visualization in Scientific Computing* [24]. While lacking a concise definition of visualization, this work is one of the first of many to repeat Hamming's admonition that "[t]he purpose of computing is insight, not numbers" [16]. Most early definitions of scientific visualization couple computing technology and graphics leading to better problem solving or the ability to understand complex or large amounts of data [24,28].

The coining of information visualization appears to have happened slightly later in 1989: "we describe an application, called Information Visualization, which uses 2D and 3D animation to explore information and its structure" [31]. The definition that is perhaps most often cited for information visualization is "the use of computer-supported, interactive, visual representations of abstract data to amplify cognition" [38]. This definition differs from the authors' definition of general visualization only in that information visualization involves 'abstract' data. Thus, the images produced by information visualization for the most part cannot be mapped literally to a spatial environment or onto a tangible, observable object such as an aircraft wing experiencing turbulent airflow.

2.1. Purpose: Discovery & Explanation

From the earliest writings, the insight derived from visualization, and hence its purposes, manifests itself in four forms: (1) Discovery, (2) Understanding, (3) Communication, and (4) Education [24,9,26]. These may be collapsed into two general purposes: (1) Discovery and (2) Explanation. Discovery involves novel problem solving or identifying an unknown phenomena or even an unknown problem. Understanding is another form of discovery that involves sense-making. This is when an investigator has a general notion of a problem or solution, but uses visualizations to solidify his or her understanding generally or to perceive the specific aspects crucial to a problem or solution. The explanatory use of visualization is its communication and educational functions.

2.2. Domain Mapping: Definition and Purpose

While their have been at least two sizable review articles of the field of domain mapping [36,39], perhaps the best and most concise definition of domain mapping is: "the graphic rendering of bibliometric data designed to provide a global view of a particular domain, the structural details of a domain, the salient characteristics of a domain (its dynamics, most cited authors or papers, bursting concepts, etc.) or all three [19]. This is yet another definition that is intertwined with the aims of the entity being defined. Again, the same four purposes of

visualization generally, apply to domain mapping: (1) Discovery, (2) Understanding, (3) Communication, and (4) Education.

3. History of Domain Mapping with Parallels to Cartography

Prior to the 1600's cartography was merely descriptive. Advances in calculating accurate locations on the planet made it scientific [17,37,25,10]. These cartographic advances include triangulation over large distances from a known base measure, using the moons of Jupiter to establish longitude on land, using accurate time pieces to establish longitude at sea, and accurately measuring depth and altitude and representing them on maps. In a sense, the same has now occurred with domain mapping. The merely descriptive has become methodologically rigorous [40,41]. A description of the algorithms for generating journal-level maps of science can be found in [5].

3.1. Descriptive Domain Maps

One of the justifications for domain maps is their long history. Descriptive, hand-drawn domain maps had long been produced prior to the advent of methodological rigorous techniques such as large scale data mining employing co-citation or bibliographic coupling. In 1939, John D. Bernal, physicist and historian and sociologist of science, produced one of the first 'maps' of science [3,6].

In 1948, Ellingham produced a beautifully hand drawn chart showing "the relations between the branches of natural science and technology." [11]. Like most domain maps, Ellingham's chart is premised on the distant-similarity metaphor (objects more similar to each other are more proximate in space.) Additional relationships are indicated by the direction of the labels. It was also intended that the two dimensional representation would be wrapped as if around a cylinder to show the continued relationships of topics on the extreme left half with those on the right. In fact, Ellingham lamented that he wished it were possible to "allow for the chart to be spread over the surface of a sphere and this would have the advantage of avoiding the need to select a particular science to occupy the center."

Furthermore, Ellingham overlay the coverage of each of the extant index and abstracting services to indicate which areas of science they covered. In this manner, Ellingham's chart is perhaps the first visual front-end to a body of literature. There have also been other hand crafted, descriptive domain maps that are seldom cited by the field [32,30].

3.2 Rise of Methodological Rigor in Domain Mapping

Eugene Garfield, a founding father of scientometrics, has always been quick to acknowledge his influences. He acknowledged Frank Shepard's legal citator [27] as part of the inspiration for the Science Citation Index and subsequent products [13,14]. In turn, his work was part of the inspiration for Page and Brin's PageRank algorithm—the foundation for Google [20,2]. Garfield acknowledged Gordon Allen's bibliographic citation network diagram of papers relating to the staining of nucleic acids as the departure point for his pictorial map of the history of the discovery of the DNA code [15] which validated and expanded upon the historical account by Isaac Asimov [1]. This appears to be the first mapping of a domain employing methodological rigor—the use of citations to establish the relationships between papers rather than the mere interpretive warrant or subject expertise of the creator.

Subsequently in 1965, de Solla Price conducted an extensive bibliographic analysis of the citation patterns of scientific papers. In addition to producing several charts and matrixes, de Solla Price contemplated that his technique could "lead to a method for delineating the topography of current scientific literature." He went on to refer to his proposed topography as a map [42].

1n 1968, Price & Schiminovich used bibliographic coupling to map the literature of high energy physics. [29]. Producing simple domain maps in the form of graphs, papers with a higher percentage of common citations were portrayed as being linked together with thicker edges. The next jump in methodological rigor was the simultaneous, yet independent, discovery of using co-citation to map bodies of literature. This was done by Small working in the United States and Marshakova working independently in the Soviet Union [33,23].

The above examples illustrate the first rigorously associative techniques used to create domain maps: (1) direct citation, (2) bibliographic coupling (the amount of citations two items have in common) or (3) co-citation (two earlier works being cited together by a third work.) Ever since, the association techniques have become more sophisticated, the methods of spatial layout have become automated and more rigorous, and the datasets from which the domain maps are created have become ever larger [5]. In this fashion, domain mapping has moved from the descriptive to the methodologically rigorous (and thus scientific)—paralleling the same development in the field of cartography.

4. Use, Adoption, and Implementation of Domain Maps

Potentially, there are six phases in the use, adoption, and implementation of domain maps. The first two have already occurred and the remaining, prospective four could happen in any order.

> (1) [B]ibliometricians realized that they could use bibliographic datasets and techniques such as author co-occurrence to provide maps of a particular discipline.
> (2) [T]he implementation of automated techniques for data harvesting, processing, and

information visualization that has facilitated the mapping of larger domains.

(3) Domain maps will become widely known outside of information science. They will become popular with educators and will be used to enhance classroom pedagogy.

(4) The widespread use of domain maps will lead to steps that aim to harmonize and better preserve the scholarly data from which they are created.

(5) Domain maps will routinely be used as one of the access options to digital libraries and online public access systems (OPAC's). See [4].

(6) Dynamic domain maps will capture and portray the diffusion of information. Domain maps will have predictive elements that will forecast and model the spread of knowledge.

[19]

4.1 Domain Maps in Education

It is appropriate that one of the most prominent discoveries in science (the structure of DNA) was accomplished using spatial modeling [35]. Furthermore, the subsequent historical telling of the process of the discovery of DNA was one of the first spatial layouts of a bibliographic representation of a field of research [15]. Similarly, this same discovery of the structure of DNA through spatial modeling was more recently the lead off story in a call to bring spatial thinking to more areas of education [8]. This spatial thinking called for in education can, in part, be supplied by the use of domain maps [19]. Concepts maps are already widely used in the field of education. They contain explicitly labeled connections [43]. These linear connections are a powerful grouping principle that conveys to the user the association between concepts. The fact that the connections are explicitly labeled allows the viewer to utilize both textual and spatial memory storage areas of his or her brain [19].

4.2 Neural Theory of Metaphor and Knowledge

In their 2003 afterword to their famous 1980 book, Lakoff and Johnson survey current cognitive theory as it relates to metaphors [45]. The two authors point to neural theory for the best explanation of how metaphors work. The human brain functions as a result of neural circuitry. It is made up of billions of biologically and chemically linked cells called neurons. During sensory experiences, different neural clusters are activated. Associations between different sensory experiences result from consistent co-activation of different clusters of neurons. Eventually, these associations become fixed via the "recruitment of neural circuitry linking them" [45 at 259]. In a similar process, abstract concepts also become linked. This gives rise to metaphors in which "highly structured neural ensembles in different regions of the brain" [45 at 256] are associated together through repeated co-activation. Lakoff and Johnson speculate that the intricacies of neural associations provide the basis for "a unified theory of thought and language based on neural computation" [45 at .271]. In other words, all knowledge is built upon a series of ever more complex neural associations.

Domain maps leverage spatial metaphors to make associations between concepts apparent to the viewer [46]. Consistent with the neural theory of metaphor and knowledge, it is hoped that viewing a representation of the structural aspects of a domain, will facilitate the creation of associations in the various regions of the brain between the concepts viewed on the domain map.

4.3 Domain Maps as Front-Ends to Literatures

As anticipated by Ellingham, domain maps can be useful front-ends to a body of literature or online learning environments [4,18]. By navigating the literature while interacting with a domain map, the user has the potential of sub-consciously and effortlessly internalizing the structure of the domain. Furthermore, a user might be able to infer knowledge about an unknown category based on its adjacencies to known categories. Such assertions await rigorous user-testing. **Figure 1** is a prototype of a domain map functioning as a front-end to a body of literature. It is a interactive web environment that allows a user to find bibliographic information about ARIST (Annual Review of Information Science and Technology) content while, amongst other means, navigating a domain map. It was created for a user interface design class by the author and his fellow student, Ian Aliman.

Conclusions

Domain mapping, is in part, academic storytelling [44]. This has been the partial story of the history of domain mapping. Similar to what occurred in the field of cartography, domain mapping moved from being merely descriptive to being scientifically rigorous. While domain maps intuitively resonate with some (most likely visual learners [18]), others ask what purpose they serve. Domain maps assist with the discovery, understanding, communication and teaching of knowledge. Domain maps have particular potential in the field of education and as front-ends to digital libraries.

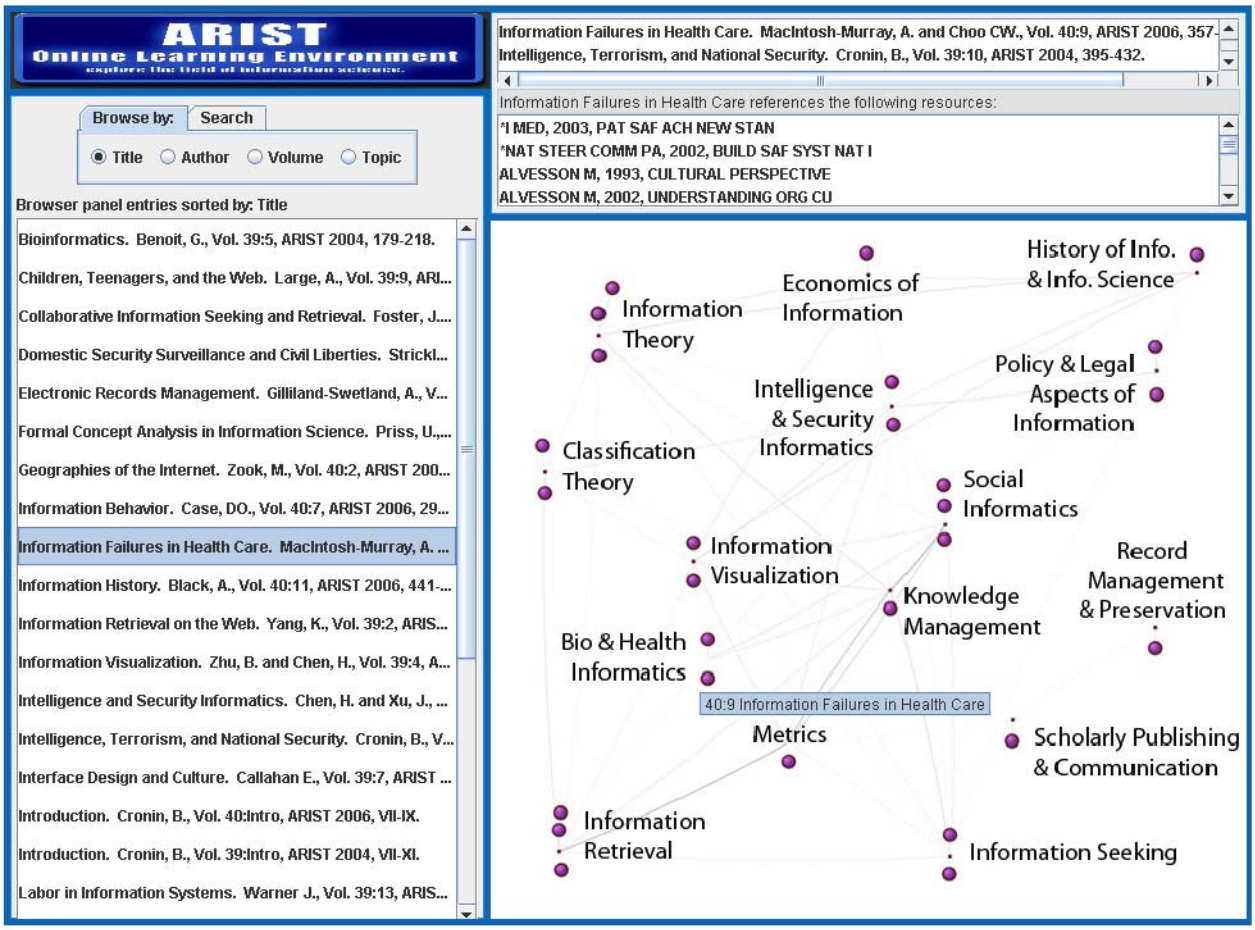

Figure 1: Screenshot of the ARIST ONLINE LEARNING ENVIRONMENT Employing a Domain Map as a Front-end to a Body of Literature, Peter A. Hook and Ian Aliman (2006)

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