This is a pre-print meant for the proceedings of the 2013 Universal Decimal Classification symposium in The Hague. Illustrations will appear later on my blog, The Scottbot Irregular, in a ppt.

From trees to webs: uprooting knowledge through visualization

Scott B. Weingart

Indiana University, Bloomington, USA

Abstract: The classification and visualization of knowledge have been interwoven for nearly as long as there are records of either. Unsurprisingly in the Judeo-Christian Greco-Roman world, visualizations and classifications most often originally aligned themselves in a branching tree of knowledge which conferred a sense of hierarchy and lineage on knowledge itself, an order which matched well with the structured cosmos of the time. These trees of knowledge spread and grew until they collapsed under their own weight by the late nineteenth century, leaving a vacuum to be filled by faceted classification systems and sprawling network visualizations. The loss of a single root as the source of knowledge signaled an epistemic shift in how knowledge is understood, the implications of which are still unfolding in present-day discussions of interdisciplinarity.

Keywords: maps of science, knowledge; hierarchy; hierarchical tree; knowledge trees; visualization; classification; networks, history of science

1. Introduction

The divisions of concepts and bodies of study have no natural kind. There are many axes against which we may compare biology to literature, but even the notion of an axis of comparison implies a commonality against which the two are related and that may not actually exist. Still, we have found the division of knowledge into subjects, disciplines or fields a useful practice since before Aristotle. These divisions are often organized into metaphors, which, in turn, influence our understanding of knowledge itself. Structured or diffuse; overlapping or separate; rooted or free; fractals or divisions; these metaphors inform how we think about thinking, and they lend themselves to visual representations which construct and reinforce our notions of the order of knowledge.

This particular narrative is organized in the standard fashion, with a beginning and an end, along a single dimension moving inexorably forward: a time-line. No doubt there are other, more compelling, forms this narrative might take; ones, which take into account the complexity interwoven in history. Those intricacies are better left for book-length study. This grand tour begins at the Tree and ends at the Web, through two thousand years of the Judeo-Christian Greco-Roman world. Fittingly, the narrative also begins with a metaphorical tree and ends with a metaphorical web. The conflation of the metaphorical with the physical, the conceptual with the visual, is no coincidence.

The biblical rooting of the trees of life and knowledge ensured the prominence of arboreal visual metaphors for centuries to come. By the twelfth century, a widely legible visual language existed which connected the tree to the order of the day: hierarchies and lineages (Klapisch-Zuber, 2007: 294). Families, morals, and religious tenets came to be symbolized by the tree, and soon enough knowledge itself became ordered through its branches. Where once knowledge existed on a simple line, beginning with man and ending at the divine, hierarchies began separating and relating disparate areas of study.

Trees embodied a medieval obsession with dichotomies, where every concept or thing had its natural counterpart; their images could easily represent the juxtapositions and divisions built into dichotomous thinking. This structuring culminated with the encyclopedists, who organized the knowledge in their encyclopedias into vast hierarchically nested trees, a trend~~,~~ which continued and found its way into early classification systems. The advent of faceted classifications broke the strict hierarchy at a time when graph drawings, a form of tree with no discernible hierarchy or specific root, were becoming popular for the first time. As the World Wide Web gains prominence and visualizations of vast networks become the norm, representations of the order of knowledge begin to take similar form.

Daston & Galison (2007) argue that, as much as visualizations are used to represent previously held conceptualizations, they also go a long way in constructing and reinforcing the objects of knowledge. The slow shift of visual knowledge representation is similarly affecting our sense of the structure of knowledge orders, from being carefully differentiated and hierarchical to being diffuse and interconnected. We have uprooted knowledge, sending it from the trees to the clouds. The careful cosmos of ancient knowledge has been replaced by a chaos of disciplines. Modern discussions of interdisciplinarity require a sense of individualized disciplines with no central structure, and indeed both disciplines and interdisciplines arrived at the same time, codependent upon one another (Abbott, 2001: 132). This co-creation of meaning and visualization in knowledge orders will be the focus of this paper. It will describe orders of knowledge from biblical trees to genealogical and conceptual ones. Furthermore, the paper will briefly discuss encyclopedia indices and interpretation of the tree metaphor in hierarchical and multidimensional classifications such as Universal Decimal Classification (UDC) and the Colon Classification (CC). Finally, I will describe the transition into the sprawling networked maps of science we see today.

2. The Tree

In the beginning was The Tree. Different cultures began with different trees, of course, but the symbol unsurprisingly appears across many religions and many histories. The *Old Testament* juxtaposes two trees, one of life and one of the knowledge of good and evil. The theme is brought up once again in the *Bible* through the Jesse Tree, a family tree tracing Christ back to King David. Symbolically and diagrammatically, for a number of reasons, trees achieved popularity in Western thought for many centuries. Visual and conceptual representations of 'relationships' tended toward dichotomies and hierarchies, often manifesting in trees and tree-like structures. By the sixth century C.E., tree structures were being used to classify ideas and organize information. These structures invariably had central roots and trunks, grounding the conceptual maps and holding them together.

According to Seneca and Pliny, tree-like diagrams of family lineage trace back at least to ancient Rome (Franklin, 1999); they reached phenomenal popularity by the Middle Ages (Murdoch, 1984). Trees were ideal structures for representing medieval dichotomies and divisions, as evidenced early by the Porphyrian tree. In the third century C.E., Porphyry classified Aristotle's Categories into a series of branching dichotomies; by the sixth century, the metaphorical tree of Poryphry was illustrated as an actual tree in Latin translations of his work. The tree separates 'Substance' into that which is thinking, and that which is extended. Branching off from extended substance is 'Body,' which itself can be animate or inanimate. The tree continues down the line until it defines the place of individual humans, like Plato or Socrates, into the grand classification of categories. Illustrations of Porphyry's tree show a very visible trunk on which families of things reside, and then use the branches to represent dichotomies within each family.

An illustration in an early eleventh century manuscript on grammar depicts knowledge, not as a tree, but more like a hub with spokes. It separated practical knowledge into ethics, economics and politics. While the scribe did not invoke the tree imagery, the rooted parts-of-a-whole hierarchical relationship still persisted. A similar twelfth century manuscript illustration begins with a central circle for philosophy and separates it out into circles for natural, ethical and rational knowledge. Each is further separated into other circles; rational knowledge into grammar, dialectic and rhetoric and the others into their own constituent parts. Several other illustrations have been found around the twelfth century with similar features, focusing on overarching concepts and their dichotomies. Non-hierarchical concept maps were rare or entirely absent (Murdoch, 1984).

Murdoch (1984) lists two more circle-based hierarchical diagrams which organize knowledge, these coming from a single fourteenth century manuscript. In the first illustration, not dissimilar from many of the time, God is listed as the root from which the branches spread. Virtus and scientia are the two branches from God; each is further divided a number of times, with sapientia under scientia and from there, Aristotle's classification of the sciences. The circle-tree illustration on the following page is rooted in the devil and branches off into various sorts of wicked knowledge like sins and fallacies. Murdoch also shows that some trees are drawn more literally than the others. One fourteenth century manuscript features an illustration of a natural looking tree, complete with leaves and branches, upon which Aristotelian logic is described and dichotomized.

Trees are also visible in the works of students. A horizontal tree drawn by the hand of a student appeared in a fifteenth century manuscript as a sort of study aid (Murdoch, 1984). It began with the root of mathematical knowledge and divided into those which are discrete, and those~~,~~ which are continuous. Continuous numerical studies (of which music was an example) were further divided into geometry, weight, light or motion, and the subjects were divided further from there. Under each subject, the scribe listed the relevant reference, e.g., Euclid for geometry, potentially as a way of organizing and remembering books.

Pacioli's fifteenth century *Summa de arithmetica* contained a 'tree of proportions,' an illustration of the various possible types of proportions (Franklin, 1999). As with the Poryphrian tree, it began with one root and branched out into dichotomies. Of the geometric proportions, for example, one variety was continuous and the other discontinuous; of continuous geometric proportions, one variety was rational and the other irrational. The branches of varieties of proportions split further and further until the scribe stops drawing branches and claims they would continue indefinitely off the page. Here again is a key concept rooted down with dichotomies branching outward, organized in a structured hierarchy worthy of the order of the medieval cosmos.

In short, and in general, illustrations of conceptual relationships were represented in tree-like hierarchies. These trees featured single roots from which all knowledge branched, based either in an ancient knowledge category or, perhaps more frequently, in God or some angelic form. It is no coincidence that the other major category of tree illustrations, family lineages, also often traced back to a religious root. The ordered structure of the world dominated medieval European learning, and these trees of knowledge grew out of a necessity to put concepts in their proper cosmological place. By the end of the middle ages, these circle-and-line tree diagrams were common enough to be decipherable across Europe (Kruja et al., 2002; Klapisch-Zuber, 2007). By this time as well, tree-like structures were extremely common organizing frameworks of encyclopedic texts (Kay, 2007).

Over time, direct association of God or angels as the root of knowledge became less visible, though not entirely absent. In the early seventeenth century, Francis Bacon wrote "the distributions and partitions of knowledge are [...] like branches of a tree that meet in a stem, which hath a dimension and quantity of entireness and continuance, before it come to discontinue and break itself into arms and boughs." (Bacon, 1765: 42). Bacon's tree detached natural knowledge from divine wisdom (Klapisch-Zuber, 2007). Descartes' seventeenth century *Principles of Philosophy*, on the other hand, puts thought - particularly metaphysics - at the foundation of the tree of knowledge (Descartes, 1913). For Descartes, thought and God went hand-in-hand, and the base of the tree also represented God's principle attributes (Ariew, 1992). He writes "Thus, all Philosophy is like a tree, of which Metaphysics is the root, Physics the trunk, and all other sciences the branches that grow out of this trunk, which are reduced to three principal, namely, Medicine, Mechanics, and Ethics." (ibid.: 119). Descartes' ordering is based upon disciplinary foundations, one into another, and how the objects of the various studies relate to one another. It again had one and only one root, with branches stretching out one from the other. That this tree-like thinking is so prevalent in Descartes is particularly remarkable given his insistence on mind/body dualism. One would imagine that each of the primitives would be a trunk to a separate tree; instead, Descartes suggests medicine, a mind/body interaction, branches wholly from physics, a set of body/body interactions. Even as Descartes' philosophy suggested movement away from a unified hierarchical structure of knowledge, the historical prevalence of trees rooted him to their use in the face of more appropriate representations.

Well into Early Modern Europe, the arboreal symbolism deeply connected biblical to scientific knowledge. The myth of Newton's apple tree, his gateway to the knowledge of gravity, was likely attributable to this connection (Epstein, 1979). A seventeenth century poet, Abraham Cowley, wrote a verse about the tree of knowledge invoking both that of Porphyry and the *Bible*: "That right Porphyrian Tree which did true Logick shew // Each Leaf did learned Notions give, // And th' Apples were Demonstrative." (Cowley, 1881: 145). Many other roughly contemporary thinkers also tried their hands at a unified system of knowledge ~~as well~~, including Leibniz, Locke, Kant, Spinoza, Gassendi and Mersenne (Flint, 1904; Biener, 2008). In chapter 9 of *Leviathan*, for example, Hobbes indexes his own classification of knowledge, beginning with philosophy and branching out to natural philosophy and politics, and branching many times further from there (Hobbes, [1676]).

The eighteenth century encyclopedists would eventually reject this kind of 'genealogical order,' as they called it, suggesting there to be an infinite number of possible orders to knowledge. Diderot and d'Alembert both claimed that unified orders of knowledge such as those of Descartes or his predecessors were essentially arbitrary; indeed, there were as many different systems as there were different ~~projects~~ of the world map (Ariew, 1992). In rejecting the definitive order of knowledge, however, the encyclopedists were faced with a dilemma: their great encyclopedias still needed to be organized into some order. D'Alembert was forced to, eventually, use a single genealogical order, at least partially: "We have chosen a division which has appeared to us most nearly satisfactory for the encyclopedia arrangement of our knowledge and, at the same time, for its genealogical arrangement." (D'Alembert, 1995: 49).

For all their wishes to rid themselves of a unified genealogy of science, the requirement to organize their encyclopedias and the logic of using traditional genealogical representations has connected Diderot and d'Alembert to the same hierarchical trees as their predecessors. Chrétien Roth's 1769 diagram of all the sciences and the arts illustrated the encyclopedia using an actual tree with hundreds of branches. Diderot and d'Alembert's own diagram of their encyclopedia's organization, while not an actual tree, still retained the same hierarchy they attempted to distance themselves from (Heller, 2013). The preface of the third edition of the *Encyclopaedia Britannica* (1797) attempted to distance itself from the earlier encyclopedias and their general classification systems. Later editions of *Britannica* noted that, although it was wise of d'Alembert to distinguish between the genealogy of the sciences and their arrangement on an intellectual map - a relatively new distinction - the use of such a map still undermined the inherent disunity of the sciences. The sciences were instead "perpetually blended in almost every branch of human knowledge," one of the *Britannica* authors noted (Yeo, 1991).

Although these comments were early indicators of a movement away from strict hierarchical views of knowledge, they were by no means the death knell. Later encyclopedias, like Samuel Taylor Coleridge's *Metropolitana*, were organized under an assumed genealogical and hierarchical scientific unity. Even in Coleridge's description, however, there is a visible movement away from the single-rooted tree of knowledge to one of multiple roots; in this case, Pure Sciences, Mixed & Applied Sciences, Biographical & Historical Knowledge and Miscellaneous & Lexicographical Knowledge (Coleridge, 1818). Though Coleridge's encyclopedia does away with the proverbial root, it still shares one important feature of rooted trees of knowledge: the encyclopedia is meant to be read in order, with all references of current articles pointing to previous ones, suggesting there to be a natural progression of knowledge beginning with the Pure Sciences. In spite of a few exceptions, like that of Coleridge, by the mid nineteenth century encyclopedias had moved away from attempting to systematically classify the unification of knowledge. What replaced the unity of knowledge was not disconnected chaos, however, but an organization of knowledge into separate, distinct, and loosely connected disciplines (Yeo, 1991).

Perhaps the ultimate culmination and conclusion of these hierarchical classifications of knowledge comes in the form of Charles Peirce's architectonic philosophy (Atkin, 2005). Peirce's late nineteenth century work continued the earlier nineteenth century tradition of Auguste Comte, who classified the sciences into hierarchically nested subjects according to which sciences provided general laws for which others, answering the question of how the sciences reduced into one another. Peirce's sprawling classification system, though without any individual root, fell well within the Kantian tradition of a single unambiguous structure of knowledge which can eventually be reached.

When H. G. Wells revisited the encyclopedic drive in his *World Brain* (Wells 1937; 1938), discussing a new world encyclopedia, he illustrated the domains of knowledge not as an encyclopedia ought to be organized, but as a student ought to be taught through grade school. Although his diagram is not a genealogy of knowledge, it is notable that he still presents the structure as a branching tree whose root is not God or philosophy, but the natural curiosity of the child. At the top of the diagram, a sun-like burst casts light on each of the branching scientific domains, with the caption "knowledge correlated through a world encyclopedia." Here, then, is a fusion of the tree and the interconnected web, and a worthy place to transition to the discussion of webs.

3. The Web

The story of the web is also an old one. By 'web', I purposefully do not differentiate between many metaphorical or literal definitions: this section deals with webs as, among other things, visual representations of connected concepts or objects, usually more formally called graphs or networks, on top of the World Wide Web, a communication structure and content network over which information is transmitted.

While trees were by far the more common of medieval imagery, non-hierarchical networks also have precedent in the Middle Ages. Trees were useful for branching dichotomies, while network-like visualizations were better suited for juxtapositions of mirrored concepts on equal rather than subordinate footing. Originally used to illustrate logical equivalences and contradictions, squares of opposition appear at least as early as the eleventh century. These squares at their simplest feature four concepts, one at each corner, and at their most complex could include more than a dozen concepts. Each concept is then connected to every single other concept individually: in modern parlance, a fully connected network.

One square of opposition appears in a fourteenth century manuscript of Nicole Oresme, in a comment on Aristotle (Murdoch, 1984). The square represents Aristotle's related concepts of generation and corruption, with one at the top left corner and the other at the top right. The bottom corners are their opposites, that which cannot be generated or that which cannot be corrupted, and then lines are drawn and labelled between each of the four concepts. Some lines are noted as convertibles, suggesting one concept implies the other, and some as contradictories, suggesting one concept negates the other. These squares were thus used to represent concepts~~,~~ which had no natural order. It is notable that the branches of knowledge were not popularly drawn in these squares, as they were in trees; medieval knowledge was traditionally visualized as part of an order or hierarchy.

The history of network-like representations that do not connect every node (entity) with every other entity can be traced back to ancient Egypt; however they were rarely, if ever, used to connect concepts. Networks as formal representations of biological relationships between species actually predates biological representation of trees of life, appearing in some form in the sixteenth and seventeenth centuries (Ragan, 2009). Though his work did not include visualizations, Leonhard Euler (1707-1783) is often credited as the father of modern ~~network~~ theory. Formal network visualizations began appearing in the early nineteenth century (Kruja et al., 2002), concurrent with Coleridge's *Encyclopedia* and the tree-like structures of knowledge by Comte and Peirce.

Networks were becoming more well-known across many domains in the eighteenth and nineteenth centuries. This spread occurred around the same time that the last great trees of knowledge were being simultaneously published and critiqued, often within the same encyclopedias as discussed above. It should come as no surprise, then, that in 1854 (re-published 1891), Herbert Spencer decided it was once and for all time to dispense with tree imagery when representing knowledge (Trompf, 2011). He writes specifically against the notion of the sciences as the “branches of one trunk”, suggesting that the notion that “the sciences had a common origin” is fundamentally flawed. Instead, the sciences “now and again re-unite […], they severally send off and receive connecting growths; and the intercommunion has ever becoming more frequent, more intricate, more widely ramified” (Spencer, 1891: 186). Spencer later goes on to deeply criticize the notion of a “common root”, writing that “however needful a succession may be for the convenience of books and catalogues, it must be recognized as merely a convention [with no] basis either in Nature or History.” (ibid.: 223) In short, knowledge is not a rooted thing, but an up-rooted network: a non-hierarchical and non-genealogical interconnected web. For Spencer, the relationships between the sciences needed to be represented in a more multidimensional way (Van den Heuvel, 2012).

Paul Otlet (1868-1944), heavily influenced by Spencer and the Dewey Decimal System (Van Acker, 2012), co-created the UDC scheme in the early twentieth century. Using a system of combinable facets, the scheme took the multidimensionality of knowledge relationships into account far better than the earlier strict tree hierarchies. Otlet sought to represent this multidimensionality visually, moving away from the arboreal representations of the past. While he employed a large variety of visual techniques, many of Otlet’s illustrations featured non-hierarchical network-like representations of classification, with circuitous paths and no discernible trunk or preferred hierarchy (Smiraglia & Van den Heuvel, 2011; Van den Heuvel, 2012). According to Rayward (1994), this classification scheme would ideally lead to “an immense map of the domains of knowledge”. That said, none of Otlet’s illustrations nor those of his contemporaries appear utilized formal network graphs, which at the time had not yet been standardized. Instead, classification scholars tended toward attempting to represent their schemes in higher dimensions, as with 3-dimensional objects.

The early-to-mid twentieth century history of classification includes many examples of increasingly nuanced understandings of the multidimensional relationships between and within the sciences. S.R. Ranganathan, drawing inspiration from Otlet, created the fully faceted colon classification scheme in 1933, which is hierarchical but allows knowledge to be classified flexibly and in many dimensions. J. H. Shera, in 1951, writes on the incompatibility of traditional hierarchical schematizations of knowledge with the actual multidimensional nature of the intellectual space (Van den Heuvel, 2012).

These movements away from inflexible tree structures in classification ran in parallel but are largely unrelated to attempts of others to visualize the space of knowledge domains as up-rooted trees straying further and further away from strict hierarchies. One map from 1939, designed by Bernard H. Porter for the Central Science Co. and republished in various early physics textbooks, puts physics and its history on a geographical landscape. This unusually historical map situates science in a direct and fated narrative, with each pioneering physicist leading inexorably to the next until the physics of the present day is reached. Although it is genealogical, it is not hierarchical: the sciences come from many places, and in places disconnect or converge.

That same year, physicist and historian John D. Bernal illustrated *The Social Function of Science* with a diagram~~,~~ which at first glance is reminiscent of the earlier tree illustrations dividing subjects within encyclopedias. History is divided into archaeology and economic history; those break out into psychology, sociology and so forth; physics is divided into optics and electricity and more. In the end, over a hundred disciplines appear in the hierarchy. What makes his tree different is that arrows cross these hierarchies, representing sideways relationships, showing that although disciplines can be divided into areas of increasing specificity, they also interact with one another in non-linear ways (Bernal, 1944; Börner, 2010).

A decade later, in 1948, chemist H. J. T. Ellingham produced a hand-drawn map showing the relationships between the branches of science and technology (Börner, 2010). While visually similar to H. G. Wells map - a full page of squares perfectly fitting against one another, with each knowledge domain occupying a square - the fundamental difference is the lack of any discernible hierarchy. In its place are just the relationships of spatial distance: the closer the disciplines, the more related they are. Ellingham used this map as a way to direct practitioners of science toward scientific literature by drawing clouds overlapping and between disciplinary squares.

In 1968, Francis Narin and George Benn drew up a diagram tracing the history of the video tape recorder (Börner, 2010). The diagram is notable for how it shows disparate areas of research connecting with one another and converging onto the tape recorder in a multitude of complex ways, using a formal network graph to represent the web of interconnections. The previous four examples from Ellingham, Bernal, Porter and Narin, show that the departure from tree conceptualizations of knowledge was not merely an interest of classification experts, but something clearly on the mind of practicing scholars and scientists as well.

It was not until the 1950s that modern-style network visualizations reached standard use across many domains, and not until the 1970s that computers made relatively complex networks easy to visualize (Freeman, 2000). Over this same period, researchers had begun drawing citation networks between scientific articles and books. Even the most genealogical among these diagrams shied away from formal trees, highlighting instead the interlinkages between scientific literature. Paper citations eventually abstracted to author or journal, which themselves eventually abstracted to citation or information networks between disciplines or knowledge domains. These maps were sometimes represented as formal network graphs, other times as spatial distance graphs, but by this time, the tree metaphor was rarely invoked.

By 1975, large scale citation and clustering analyses were being used to map the macrostructures of knowledge domains and their relationships to one another, and by 1985 the entire ISI (Institute for Scientific Information) citation index datasets were being used for this purpose (Small & Garfield, 1985). Within a decade, sophisticated techniques were being used to map both internal and external structures of science, combining nested sub-disciplines and connections between them (Small, 1999). Ten years later, enough science maps existed to warrant a consolidation and standardization effort (Klavans & Boyack, 2009). Klavans & Boyack, in making a consensus map of science, are quick to point out that these maps do not attempt to correspond to "an ontology of knowledge". This is a far stretch from medieval knowledge maps, which illustrated the relationships between concepts as they actually were, or even eighteenth and nineteenth century visualizations of the universe of encyclopedic knowledge, which often represented genealogies or at least one possible ontology of knowledge. Modern maps of science have displaced both the formal hierarchies of what came before, as well the notion that these illustrations represent any more than a useful way of understanding and navigating social and structural landscape of science as it is practiced. They also displace the central root of science, opting instead for a diffuse and rootless concept of knowledge. As C. S. Lewis (1943) wrote in an unrelated but apt quotation, "there seems no centre because it is all centre."

Alongside the growth of citation analysis and science mapping, the well-known story beginning with Vannevar Bush's *As We May Think* (1945) and spanning the next half-century unfolds, tracing the growth of hypertext and eventually the World Wide Web. One solution to navigating the world's information, suggested by Ted Nelson (1974), was the Xanadu project. It was "a new form of interconnection for computer files - corresponding to the true interconnection of ideas - which can be refined and elaborated into a shared network" (ibid.: 143). After the development of the World Wide Web, Nelson fought against the use of hierarchies in organizing knowledge, preferring a multidimensional method of navigation, and creating some network-like visualizations to support this concept (Van den Heuvel, 2012). Many network-based visualizations have since been published mapping both the web in general, and knowledge domains in particular (Bollen et al., 2009).

Given the engagement of the classification community with the web community and bibliometricians, both of whom have employed ample use of network and other non-hierarchical visualizations, it is perhaps surprising that visualizations of their own systems have been relatively sparse after trees fell out of vogue (Klavans & Boyack, 2009). There certainly have been attempts, (Beaudoin, Parent & Vroomen, 1996; Herrero-Solana et al., 2006), and science mappers often rely on pre-existing classification schemes to cluster their objects (e.g., Bollen et al., 2009), however only quite recently have serious attempts been made to visualize traditional classification schemes (Akdag Salah et al., 2011; Van den Heuvel

& Akdag Salah, 2011). While those recent examples opt to visualize the UDC structure as a circular network, thus displacing the implicit value-granting of a linear hierarchy, they still fall short of moving beyond the tree structures that early classification pioneers attempted to distance themselves from.

With this in mind, it is the perfect moment for this International UDC Seminar on connecting classification to visualization. The time is ripe for moving beyond the arboreal visual metaphor, which has long-since outlived its rhetorical usefulness in the face of faceted classification schemes and multidimensional ontologies of knowledge. A brief glance at the authors and titles of presentations at this seminar shows that scholars are already considering these issues and, together, are equipped and ready to create new visual metaphors of concept classification that capture its nuances and complexities, uprooting the outmoded hierarchical trees in favour of a malleable interconnected web of ideas.

4. Solidification of ontological diffusion

A final note needs mentioning with respect to a thousand years of slow movement from linear hierarchies to diffuse webs in the popular representation of knowledge domains in the Western world. In her work on observation, Lorraine Daston (2008) explores the relationship between what scientists consider to be observable units, and how they visualize those units. She writes of Ludwik Fleck and his microscopic observations of bacteria, who wrote that the novice sees only blobs when looking under the microscope, whereas with training, the expert can finally discern things. With that training, however, the expert loses the ability to see anything that contradicts the form which he knows to be visible. As Daston writes, "perception furnishes the universe. It doesn't create the universe, but it does shape and sort, outlining sharp edges and arranging parts into wholes" (ibid.: 100). Scientific perception of objects is a deeply psychological affair.

Collective and continuous observations create scientific objects, such that the chaos of ever-changing clouds in the sky can eventually be dissected and classified to the various forms we know today (cirrostratus, cumulonimbus, etc.). An important step in the creation of these scientific objects is the act of illustration, which distills and unifies many observations into their defining characteristics, as with the cloud atlas of the late nineteenth century. This is true not only of naturally perceived phenomena, but of more abstract scientific visualizations like graphs or pie charts; distilling data in a certain way reinforces that distillation until it becomes a basic unit of scientific knowledge - a thing. And things, scientific objects, form the basis of what we now consider to be true and objective (Daston & Galison, 1992; 2007). While a visual language works toward solidifying scientific objects, communities of practice gather around and are defined by their use of those visualized objects (Rudwick, 1976). The nature of those scientific objects then shape the path and the epistemic values of that scientific community in subtle but powerful ways (Huber, 2011).

With this in mind, there is a deeply normative and moral angle to a self-conscious shift in visualization strategies. A modern world ever-filling with visualizations and rhetorical structures which emphasize networks and webs as representations of society and knowledge and nature in turn reinforce our tendency to see these webs in places they are perhaps not as relevant. If the conscious decision is made to begin aligning knowledge classification structures with the web-like visualizations now common in other domains, a scholarly society already primed to networked thinking and the de-centring of hierarchies will only further lose any sense of primacy or order in its ontology of knowledge. The carefully structured cosmos of ancient knowledge would be further supplanted by the chaos of disciplines. At its most absurd logical conclusion, no domain of knowledge or pseudoscience would have any genealogical or epistemological claim to superiority or centrality when the ontology of knowledge itself can make no claims to either. While this conceptualization may fit nicely within some conceptualizations of a post-modern world, some might find fault with the premise. At this Seminar, a new direction for the visual language of classification may be put in place. While it is important to take further steps to make sure visualizations align with their conceptualizations, caution is also warranted when the conceptualization of the structure of knowledge is itself at stake.

Acknowledgments

This research was conducted under the support of a National Science Foundation Graduate Research Fellowship. I would like to thank the initial comments and assistance of Charles van den Heuvel and the continuous advice of Katy Börner.

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SCOTT B. WEINGART researches information science and history of science at Indiana University. His studies focus on scientific communication and collaboration, both in early modern Europe through correspondence networks and early journals, and today in modern citation and publication patterns.

Scott is an NSF Graduate Research Fellow, a Paul Fortier Prize Winner for the Digital Humanities, and the author of the scottbot irregular, a blog covering computational methods and tools for humanists. Scott also aids in the development of software for data analysis, modeling, and visualization at the Cyberinfrastructure for Network Science Center at Indiana University.