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Visual Displays of Information: A Conceptual Taxonomy

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This paper creates a taxonomic model for visual information displays looking at three levels: information design (based on Edward Tufte's work), information architecture, and information spaces. Special attention is paid to the use of spatial and navigational metaphors in visual systems as they affect the user's experience. Especially interesting is how a user creates an "information space" – a mental model of what he has seen, how she keeps track of where she is within a system, and how these activities fit together with the data that is being sought. Mathematics is one area that holds promise for better understanding how people visualize information spaces. Vague terms like space, shape, and distance (all implied by the navigation metaphor) have far more refined conceptualizations within mathematics. By harnessing the descriptive powers of mathematics, we can more aptly describe and understand the process of metaphor creation. Secondly, studying comic books and how they are read (McCloud 1993) holds much promise for understanding how people navigate electronic systems. Comics are 2-D sequentially arranged (or at least juxtaposed) combinations of images and text, much like computer screens. People used to reading such visual constructions are better able to navigate through complex information systems. Finally, the use of spatial or navigational metaphors necessarily implies a temporal dimension as well, which leads to certain subtle, but important differences when comparing navigation through electronic environments as opposed to real world ones.

Introduction

Visual displays of information are an important and increasingly vibrant field of research and practice that holds great promise and opportunity for the future of libraries. The phrase "visual information displays" encompasses an enormous range of activities ranging from the familiar such as World Wide Web pages and computer interfaces to the more esoteric like semantic spaces and information shape. Yet it is possible to develop a working model of the entire field by grouping what might at first seem like disparate activities into a coherent structure based on a shared goal: the act of effective, efficient, and easy information retrieval and display using visual means. Placing the many forms of visual display along an axis that moves from the most limited in conceptual scope and thus most practical in application to the most abstract and theoretical and thus not readily applicable outside of discussion is a fruitful methodology for analysis. Three conceptual levels are sufficient to understand visual information: 1) information displays (or visual design), 2) information architecture, and 3) information space. Here information space denotes how users internally conceptualize their experience of an information architecture and how, or whether, that conceptualization is understood and processed in visual terms.

These three levels are related with each subsequent term necessarily encompassing the scope and methodology of the prior term(s). The use of this model allows the discussion of everything from paper graphs to user interfaces to virtual reality to how users conceptually map their knowledge universes, all with a regard to information displayed visually.

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It is misleading to assume that visual information was non-existent before the computer graphics developments of the 1990s. Edward Tufte's work provides a smorgasbord of examples of visual communication preceding the computer including train schedules, a chronology of Soviet cosmonaut activity, landscape renderings, and many others. It is true however that, until recently, "the history of information retrieval [and this is really what information display is all about] is mostly the history of word retrieval" (Lunin 1999, 790). The advent of graphical user interfaces (GUIs) and contemporary computer processing ability has, of course, launched a revolution in using visual techniques both to communicate and to retrieve information [1].

Displaying information in a visual or graphic form can be (if done right) inherently strong, robust, and effective. A large body of evidence suggests this is true. Richard Wurman in *Follow the Yellow Brick Road*, a study of how to provide effective instructions, says that "what has come through in many studies is that the combination of pictures and words is more effective than either alone." (1992, 186). A special report on visual information in the *Journal of the American Society of Information Science* asked whether visual displays are "of greater power than the ordering of retrieved objects by lists?" and answered with "All the authors in this issue claim that it is a more powerful vision. Moreover this claim is made on the face validation presented by our human senses and the pre-linguistic evolutionary properties of the human visual neocortex" (Lunin 1999, 790).

Computer graphics create a user-tailored display that is capable of (at least limited) change from session to session. This non-fixed capacity is what really powers the growing utility of contemporary visual displays: it frees the user from a strictly linear narrative that previously reigned supreme in textual displays and allows for a more than two-dimensional display. Once the linear display structure is removed and replaced by an at least partially nonsequential structure, visual information displays become enormously more powerful, but also complex, in their functioning.

Tied ineluctably to this capability is that of interactivity. A user now not only can view information and process it in her mind, but also influence the creation and display of a given data set. Together interactivity and nonlinearity lead from simple principles of good visual design towards information architecture and then to information space.

Information displays

First though, defining visual design or information display, the most concrete and established of the three levels, is prudent. Edward Tufte has created the Bibles for effective design of visual information displays. In all of his books Tufte argues that "clarity and excellence in thinking is very much like clarity and excellence in the display of data. When principles of design replicate principles of thought, the act of arranging information becomes an insight." (1983, 9). Tufte's three volumes, *The Visual Display of Quantitative Information*, *Envisioning Information*, and *Visual Explanations* are meant to convey design principles about pictures representing numbers, nouns, and verbs, respectively. Across these three areas the design principles remain relatively constant and are easily described.

Tufte, above all else, stresses clarity of presentation. He notes that "clarity and simplicity are completely opposite of simple-mindedness" (1990, 34). Tufte says that clarity can be accomplished in visual displays (of any form and format) by utilizing the following principles:

1. To clarify, add sufficient detail.
2. Show the data. Never obscure or hide data.
3. Strive for high information density per display.
4. Reduce chartjunk and any form of extraneous clutter.
5. Assume the audience is intelligent.
6. Proper use of spacing, layout, and color is essential.

While these principles embody a host of more detailed rules and procedures, they possess enough generality to serve as a template for effective design and discussion in a variety of situations. Though Tufte believes that presentation should be kept as simple as possible, allowing for complex formulation and extraction of information from data sets, the data itself should not be compromised. Tufte's advice is very practical; it focuses on allowing a user to extract maximum information from a visual information display. Items like color use and layout

design are already fully realized in the graphic design world. These principles are not always used, however, in computer displays. Tufte has harsh words for computer display systems, saying that most spend too much effort on extraneous display and not enough on relevant information.

Information architecture

When a computer not only displays information graphically, but allows for its sifting and configuration and when the given display is part of a much larger information entity with a variety of possible display pages which are interconnected (topically and navigationally) in some fashion, then the level of analysis shifts from information display to information architecture. The salient issue ceases to be how each page can be most effectively constructed to how these hopefully well-designed pages may best be configured as a structured system for the maximum user utility in extracting information.

Completely new issues arise at the information architecture level. First, unlike each single page display, this level assumes the use of computers and screens [2]. Thus, this field, unlike regular page design, has very few historical antecedents. As a term, as an intellectual field, and as an endeavor, information architecture is only about five years old. Information architecture has, however, already achieved recognition as a vital element in successful user functioning. Clifford Mok, in *Designing Business: Multiple Media, Multiple Disciplines* defines information architecture as:

1. The meaningful organization of information, giving it shape within the complex structures behind the computer screen. (1996, 97)
2. The integration of the structures underlying a system. (1996, 98)
3. The thoughtful arrangement of data and the navigational devices used to move amongst that data. (1996, 102)

The third definition is the one that comes closest to the everyday practical idea of information architecture and the nascent job description of information architect. Briefly put, it is arranging web sites in a well-thought out, easy to manoeuvre manner that allows a user to understand how the various pages connect both logically and navigationally.

Along with Mok's book [3], there exists a large and growing body of literature on how to make good Web sites, including Web sites themselves like www.webmonkey.com. At the University of Wisconsin-Madison, a guideline is available for structuring sites that focuses on practical considerations like how many levels a site should contain, how many pages per level, and the choice of navigational devices. The lower level of information design persists in relevance as questions of placement and highlighting navigational features remain on each page.

Navigation and information architecture

The rationale for good information architecture is the same as that for real world architecture: to provide a welcoming place in which users will not get lost or have to travel too far to acquire what they need. However, doing this task on a flat screen is considerably challenging.

Print media, of course, have an established, well-known, fairly standardized set of hierarchical (book-chapter-page-paragraph-sentence-word) and navigational (table of contents, index, page numbering) structures developed for moving amongst a given print information architecture. This task is also rendered simpler because most texts are accessed sequentially (reference materials being a notable exception).

It is worth remembering, however, that print media's navigational and organizing techniques have had five hundred years to develop and were not all present at the dawn of the printing age. Thus the present state of ambivalence over information architecture and lack of standardization on organizational structure and navigation should not be looked at with dismay as the sign of format inferiority, but rather as the growing pains of a medium struggling to mature.

The most important point to consider when examining how users navigate is that interactivity depends on a user choosing an action out of several options. That is to say, a given display of information results from a particular choice. Whether this is a good or bad choice will depend on what the user wants (which cannot be controlled, but perhaps predicted) and the information architecture and visual design (which can be controlled).

Information architecture works when integrity of experience in a given site is maintained by re-

inforcing context and content across a variety of actions. Without this supportive structure, any interactive web site becomes a parody of information delivery, merely offering a parade of colorful, changing objects. Mok offers the following principles for information architecture (1996, 130).

1. Things should progress from simple to complex.
2. Natural constraints [computer programming] should be in place to prevent too many errors [especially for novices].
3. Functions must be apparent as such and visible at all times for whatever is required.
4. A user's focus should be on content, not format or navigation.
5. Immediate feedback from actions taken should be given to users.
6. Three modes of operation should be provided for:
   a. Command.
   b. Manipulate.
   c. Record.
7. Pace. The user should be able to control the rate of movement through material.
8. Appropriateness:
   a. The interface should accommodate users, not the other way round.
   b. The system and interface should be as customizable as possible.
   c. The fewer assumptions made about users the better.

As opposed to many books on the topic, these principles are not narrowly focused on GUI design per se, but on parameters that must be met in web site design for successful information extraction. In this sense, they function the same way as Tufte's principles do, possessing both robustness and flexibility, only at a higher level. They also focus on interactivity and thus from a librarian's point of view, must be considered relevant to database and catalog design.

The principles of good information architecture revolve around navigation and articulate how a rich contextual user experience is to be achieved because users, after all, are staring at a flat screen and not actually moving through anything real. Only a two dimensional visual display in front of them is changing, sometimes dramatically and sometimes quite subtly. An ancillary issue that complicates understanding how individuals experience information architecture is that "users may take different routes through a given architecture and …[be permitted] different levels of autonomy in doing so (from system-prescribed sequencing of information to learner-controlled navigation)" (Ford 2000, 543). Thus a given architecture may be describable and bounded in its structure, but much less describable and possibly unbounded in its navigational complexity. And of course, a given navigational sequence could transcend several distinct information architectures. Adding a final note of possible confusion is the fact that digital information may "take multiple forms such as text, sound, pictures, and animation and can easily overwhelm a user's ability to filter and represent [regardless of architecture]" (Dillon 2000, 521).

Information spaces

When we consider how a user processes and understands the meaning of her experience in utilizing and navigating a given information system (i.e. moving through a given information architecture and looking at the design), the third level in the visual information display taxonomy, an information space, has been reached. Understanding that information space in this sense denotes an abstract quantity that does not physically exist is crucial. As mentioned earlier, information space denotes how users conceptualize their experience of information architecture and how, or whether, that conceptualization is understood and processed in visual terms. While a given information architecture does not literally exist either (except as a collection of files), it does possess an organizational structure that reflects actions connecting different data elements and computer files and can be rendered pictorially without too much difficulty (see Mok's examples). Likewise, visual design elements like color and layout are more obvious and more easily discussed because they represent a common, tangible, real world experience for users.

Why is this level of visual display deemed an information space? Woolsey says, "Visual thinking is really about spatial thinking … ideas take place in space." (1996, 43). Furthermore, "the human mind has the ability to organize experience in spatial terms and recall objects associated with physical locations … It seems reasonable that cre-

ating spatial environments with information items distributed in a stable and meaningful fashion has the potential of enhancing information usability and retrieval" (Small 1999, 799).

In fact, the technique of using imagined locales to aid memory and thinking is actually a skill not much practiced today, but one that has existed since antiquity. Cicero wrote in 55 B.C. that "We must for this purpose [memory] employ a number of remarkable places, clearly envisaged and separated by short intervals: the images which we use must be active, sharply-cut and distinctive, such as may occur to the mind and strike it with rapidity" (1979, 358). Quintillian, one hundred and fifty years later, added "We may imagine such places, real or imaginary, and images or symbols, which we must, of course, invent for ourselves … in fact as Cicero says, we use "places like wax tablets and symbols in lieu of letters" (1979, 354) [4]. These passages are not just historical curiosities, but are important because the thought processes they describe are applicable to what we today are trying to accomplish. The idea of using places to aid memory is the salient idea of navigation through electronic media and therefore any and all examples of this thinking should be consulted.

Navigation and metaphor in visual systems

Thus when confronted by a situation that utilizes navigational and spatial metaphors like site, architecture, location, and surfing, all words describing physically real places, or actions that move one through a physically real space, the human mind attempts to forge a familiar artificial world to accommodate and integrate its experience in gathering information. The mind, however, only creates spatial metaphors in the presence of an environment that can be assimilated (that information systems are such environments seems to have been decided *de facto* by popular choice). An environment such as this is one where [here I use my own terms and definitions] contextual clues aid in the distinguishing of place (current location), path (the history of interaction coupled with place), and aim (the data sought, the metaphorical place that holds that data and a similar place that will present it). Coupling these three concepts together is the fact that the emerging strategy (place, path, aim) to reach the data must lie within the confines of the information space created by a user or else allow a user to redefine the definitions and boundaries of his information space in an ongoing and real time manner.

According to Andrew Dillon at the Indiana University School of Information and Library Science, most research to date has focused "on the analysis of visual navigation aids that might support users' bottom-up processing of the spatial display" (2000, 521). He goes on to say, however, that an alternative is being formulated that "places greater emphasis on the top-down application of semantic knowledge by the user gleamed from their experiences …" (Dillon 2000, 521). Using navigational aids is no doubt helpful and necessary and clearly builds on the lower level visual design and architectural frameworks. What Dillon is saying, however, is that attempting to create a fool proof type of architecture and navigational suite places too much focus on the computer system thereby locking in those who use that system. Different users confronting the same information architecture and visual design may construct their information spaces to varying degrees of comfort. And therein lies the crucial difference between visual design and information architecture on the one hand and information space on the other. Other people create the first two levels for users; users create the last by interpreting the first two levels.

Chen recently compared many diverse studies on individual learning differences to isolate the most salient characteristics that influence and mediate a user's experience of information space. Chen and his colleagues (Chen et al. 2000a, 503) created a list of four broad questions they deemed necessary to understanding any user's experiences.

1. What are the predominant human factors concerning the design of a virtual environment?
2. What is the role of individual differences in the use of a virtual environment?
3. How do we assess the effectiveness and usability of a virtual reality application?
4. How do we account for users' cognitive and behavioral experiences in a virtual world?

To this list Chen appends nine distinct issues that he claims must be addressed in order to answer any of the four questions.

1. Individual differences in virtual environments in terms of spatial ability and cognitive styles.
2. Learning in virtual environments, including cognitive models, spatial memory, incidental learning, categorization and abilities.
3. Usability and evaluation methodologies.
4. User preferences and satisfaction.
5. Analysis and modeling of user behavior, search strategies, and navigation heuristics.
6. Multiuser virtual environments, 3D interactive systems, spatial hypermedia.
7. Visualization and simulation in virtual environments.
8. Automated virtual environment generation and transformation.
9. Semantic structures and spatial structures in virtual environments.

Chen (2000b, based on earlier work by Dourish and Chalmers 1994) also studied the interplay of three metaphors for creating and using an information space: spatial navigation, semantic navigation, and social navigation. Spatial navigation is the use of geometric representations or metaphors to reify "movement". Semantic navigation refers to how users create semantic relationships to manoeuvre rather than the strictly geometric ones of spatial navigation. Social navigation is the intriguing idea that users will search within and construct their own information spaces in much the same way as like-minded individuals.

Jean Trumbo has also parsed information space (she terms it design space, but it seems to be the same construct) into more specific concepts. Trumbo says that users of multimedia break their spatial models into physical, conceptual, perceptual, and behavioral aspects (1997, 19). The most fascinating part of her analysis is the notion that design space harbors both architectural (functional) and sculptural (expressive, artistic) purposes. Some things are meant to be inhabited and moved around in (the architecture) and others to be viewed and admired (the sculptural), but visual information systems really are both. We view information and reflect upon what we are seeing, but use metaphors of movement and habitation to designate our viewing experiences. If information space is thought of as having an artistic function, then surely it should have an emotional, expressive dimension just as art does. This dimension would stand apart from the obvious cognitive and information aspects that are traditionally considered when thinking about how users interact with visual systems.

Recent trends in understanding information space also deal with semantic conceptualizations of learning and the use of spatial metaphors to describe navigation. Users must "assimilate information into their knowledge structures, an activity that extends processing beyond traversing layout [information architecture] to interpreting meaning" (Dillon 2000, 523). In addition they must gain a firm grasp of an information space by giving it "shape" (or otherwise, what are they navigating *through?*). Users are not consciously aware of constructing an information space, yet when asked to describe their experiences will attempt to draw shapes and linkages that denote a limit to how and where the information is located and how they moved through that information. To me this implies that users simultaneously embed themselves in their own information space and retain a godlike ability to see above or through that space in its entirety (or attempt to do so). In fact I think an ability to engage in and switch at will between both of these intellectual activities, at a sufficiently high performance level, would distinguish a savvy user from a struggling one in a given complex multimedia or virtual environment.

So how does an abstract concept like information space affect the library world? Most librarians will not study information spaces nor discuss them in day-to-day practice, yet such attempts to understand the extraction of information from a medium that already partially defines what it means to be a librarian are worth pursuing. If the diverse notions of information space could be bolstered by well-developed criteria for evaluation, such literature might eventually find its way into library and information studies curricula.

Moreover, in teaching database searching I have noticed that users (generally university students) have no sense of where they are located regarding where the catalog or local database begins and ends nor realize that the other databases are actually separate entities. This "seamless" environment has, of course, been a major objective for many years and yet now that it is approaching a reality, users are befuddled by the *lack* of distinction in moving from system to system. Thus, how users internalize what they see as they transition across various system resources is not translating

into an internal path, or useful space, designating how the systems are related to one another.

Future directions: Comics and mathematics

There are two disparate activities that may hold promise for shedding light on how users create information spaces. The first is mathematics. Ideas like shape, space, location, distance, and path (the last three implied by navigation) are all richly explored and more refined within mathematics. Because of my background, when I read about space and shape, I formulate those terms in a way that I suspect does not reflect common usage. Thus I wonder how ideas such as shape, mapping, and position in an abstract system are understood by those unfamiliar with mathematics. I do not want to actually perform higher mathematics in this context. Rather, I think mining mathematics for its metaphors, ideas, and conceptual understandings of shape and space might be fruitful in order to see if there is something that fits what users experience in creating an information space, but do not have the vocabulary to name, except with vague words like space and shape.

For instance, I wonder whether users think of the various pages that they view and traverse as *connected* (do they literally touch in the user's mind) to one another or as *discrete*. Is the experience of navigating through a site akin to finding the shortest path through a park in winter, when only the cleared paths can be used (so the space would be thought of only as the paths), or do users think of moving around in any possible direction like I could do in summer when I can walk on the grass too (when the space would include the area around the paths too and any path is possible)?

In another example, I tend to conceptualize information areas as "bubbles" in my mind, that vary in size and extent depending on how much information is available and in what salient subject areas it is strongest. To me these bubbles can be distorted (a topological property) and stretched (and *do not* have to be connected to one another, but *can* be). My way of internally viewing these forms makes me wonder how far a given site can be "deformed" (i.e. changed somehow) before it would lose its integrity or identity.

This use of mathematics would grow more potent, I think, as the spatial rendering of an information space became more abstract. I would like to see if the ability to richly describe an information space metaphorically, as Dillon suggests, correlates with anything else (especially spatial ability). Taking this further, do the shapes that people describe have or acquire any geometric or topologically invariant properties as a user builds a richer information space with repeated use of an architecture and/or does a given conception of information space(s) alter longitudinally with use of different information systems? Likewise, I wonder whether familiarity with a given information source, system, or architecture renders the concomitant conceptual space more expressive and whether there is a way to map these ideas and begin to locate users within a meta space whose points are made up of users' information spaces based on characteristics like shape, degree of expressiveness, robustness, boundedness, and others.

I also think it is worth studying the other graphic medium that combines text and visual images: comics or graphic novels. Scott McCloud in his wonderful *Understanding Comics* defines comics as "juxtaposed pictorial and other images [this includes text] in deliberate sequence, intended to convey information and/or produce an aesthetic response in the viewer" (1993, 9). This definition to me sounds remarkably like most contemporary information systems that rely upon visual displays. Therefore, I believe strongly that McCloud can teach us many useful things. Within western comics, for instance, there are a number of techniques for conveying duration, time, and space on a small flat panel that is linked sequentially with other panels. While this "sequentialness" means that comics do not exactly have the architecture of a computer information source, their (comics') architecture is more complicated than that of textual narratives and not strictly left to right, panel after panel. Panels can also differ in size and placement from page to page as well as in other subtle ways.

More interesting still is that while the majority of western comics change panels in an action-to-action sequence or subject-to-subject (one character to another), many Japanese comics do not. McCloud says,

> Aspect-to-aspect transitions have been an integral part of Japanese mainstream comics almost from the very beginning. Most often used to establish a mood or a sense

> of *place* [emphasis mine], time seems to stand still in these quiet contemplative combinations. Even sequence, while still an issue, seems far less important here than in other transitions. Rather than acting as a bridge between separate moments, the reader must assemble a single moment using scattered fragments. (1993, 79)

This passage echoes the assemblage that a user performs to keep track of where he is in information architecture and then begin to place the transitions that led to that mental picture into a semantic model coherent with an already formulated worldview. It would be very interesting to see if familiarity with Japanese comics (more specifically, ease with this sort of view of time and space) would influence how a person navigates and conceptualizes a complex information system.

Time and navigation

I am also surprised that in all my reading the focus was on location and movement and interpretation, with little mention of time or duration. I am not sure whether the studies of information spaces assume that time is implicit in their understanding of perceptual recognition and semantic formulation or whether no one thinks users might conceive of information sources being not just related physically or semantically, but temporally as well. Again, McCloud says "in learning to read comics we all learned to perceive time spatially for in the world of comics, time and space are one and the same." (1993, 100) and that "as a result, so too are the issues of time and motion [i.e. navigation]" (1993, 107).

The notion of space and shape used implies that when things are close together (less places in between) they are also automatically closer together in time is also worth examining. I am curious whether users think of all the possible screens they could see (places) as actually existing simultaneously in time, not beginning or ending with viewing (just as I presume France exists in time even when I am not there). This would mean having an indeterminate duration while having a precise location (an architectural assumption about place).

The alternative is that users imagine, when they navigate, that displays flicker in and out of existence with movement, thus having a measurable duration. Time becomes tied to place. This idea echoes the notion of pre- and post-coordination that librarians make use of in a controlled vocabulary. Pre-coordination refers to displays that are decided upon ahead of time. For example, doing an author search in most catalogs will result in an alphabetical list beginning with the chosen name. This list has been *pre*-established by the librarians (or more accurately, the catalogers) and is not going to change based on the user. Post-coordination, however, gives a screen display that depends very much on what a user puts into a system. Keyword searching perfectly illustrates post-coordination. The search terms may *never* have been placed together before and the resulting display (list) is entirely novel.

In real world movement, reality is pre-coordinated; we assume that both places and time are already created and continue to exist. Since the navigation metaphor is so common to understanding information spaces, it should assume that places exist whether we are there or not. And yet, post-coordination shows that techniques like keyword searching guarantee that information displays are newly created and do not enjoy duration (the display is created by and exists as long as the user remains present). Therefore even as a real world metaphor is used to describe searching experiences, the metaphor falls short because there is no real world experience akin to visiting a freshly created place whose mere existence is dependent upon the viewer's intent.

Conclusion

By focusing on different levels of abstractness, I have attempted to create a useful partitioning of activity concerning visual information displays while retaining practical and theoretical connections between the different levels. At each level, information display, information architecture, and information space, I have included what I believe are useful guidelines to creating, using, and understanding the purpose and functioning of that level. The criteria should not be thought of as checklists, but rather as templates for clear information exchange. Just as my levels become more abstract, the templates shift from statements of activity that can be readily assessed towards questions of intent and meaning that require thoughtful deliberation before answering. It is very important to realize this taxonomy is sym-

biotic in nature. What happens at any given level influences and manifests itself in the other levels.

Finally, since this entire enterprise is about the human response to emergent technology and gaining a better understanding of human-computer communication, two points should be made about visual information displays as an example of how technology intersects with social life. First, what unites information space with information architecture and any level of visual design is that "design relies upon the thoughtful consideration of human behavior" (Trumbo 1997, 23). Those who do not understand this idea or choose to ignore it risk folly.

Second, Henry Petroski, who has written at length about the sociology of technological development, argues that a good, well-designed technology ultimately becomes an invisible technology because the focus shifts from how something works to how it can be used. Given the novelty of information systems and the variety of visual displays, it is not surprising that most user attention is still riveted on successfully learning systems. No architecture is so fully developed to be intuitive for even a simple majority of all possible users. And, assuming continued technological development, truly virtual or spatial (3D) information systems may become viable, causing another shift in understanding [5]. Visual Information displays will reach their full potential in the library, regardless of their form, when the generic user no longer notices them as a technology, but transparently assumes their existence and usage much like a telephone.

Notes

1. In additon to the References section below, an annotated bibliography in the Appendix provides further information on the topic of visual displays of information.
2. The previous level, visual design, works perfectly well for paper displays, graphs, statistics, and signs; all pictorial information that libraries use.
3. Mok (1996) has beautiful renderings of site maps and case studies in information architecture design, though all of the examples are commercial.
4. For more on this topic see Francis Yates' *The Art of Memory* (1966).
5. For entertaining versions of what this scenario could look like, see Neal Stephenson's novels, *Snow Crash* (1995) and *The Diamond Age* (1992).

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Tufte, Edward. 1997. Visual Information: Images and Quantities, Evidence and Narrative. Cheshire, CN: Graphics Press.
Tufte, Edward. 2000. Home Page. 8 October 2000. URL: http://www.cs.yale.edu/people/faculty/tufte.html [viewed August 1, 2001].
Webmonkey Home Page. 2000. 20 October 2000. http://hotwired.lycos.com/webmonkey/.
Woolsey, Kristina Hooper. 1996. VizAbility: Change the Way You See the World. Boston: PWS Publishing Co.
Wurman, Richard S. 1992. Follow the Yellow Brick Road: Learning to give, take, & use instructions. New York: Bantam Books.
Yates, Frances A. 1966. The Art of Memory. Chicago: University of Chicago Press.

Appendix: Annotated Bibliography

Books

Cicero. De Oratore. Trans. E.W. Sutton and H. Rackham. Cambridge, MA: Harvard University Press, 1979.
The great Roman orator discusses the art of public speaking with a group of friends.

Cooper, Alan. About Face: The Essentials of User Interface Design. Foster City, CA: IDG Books Worldwide, Inc., 1995.
Good advice, but very, very few illustrations, making it a lot harder to gleam what his principles would actually look like in practice. More focused on precise how-to's and less on design theory or principles. Definitely from the technical side of the issue.

Cutting Edge, The Women's Resource Group, Eds. Desire by Design: Body, Territory, and New Technologies. London: I.B. Tauris Publishers, 1999.
Discusses the impact digital design and media have on gender construction, particularly for women. Asks whether interactive media are empowering or limiting and for whom, especially medical imaging devices. Extremely interesting discussion on how "spaces" are conceived, perceived, and lived in.

Druckrey, Timothy, Ed. Electronic Culture: Technology and Visual Representation.
A critical analysis of what it means to create and hold information in a digital format.

Gombrich, E.H. The Uses of images: Studies in the Social Function of Art and Visual Communication. London: Phaidon Press Limited, 1999.
See Chapter 9, Pictorial Instructions. This book looks at visual instructions as art rather than from Tufte's view as communication.

Kueger, Myron W. Artificial Reality II. 2nd Ed. Reading, MA: Addison-Wesley Publishing Company, 1991.
An extremely readable book on how various artificial systems and devices work and the social, cognitive, artistic, and intellectual ramifications that could result from their use. Very speculative and, given the publication date, worth comparing to the present day.

Lupton, Ellen. Mixing Messages: Graphic Design in Contemporary Culture. New York: Princeton Architectural Press, 1996.
Focuses on graphic design "from the printed page to the Internet" during 1980 to 1995. Especially good for contrasting techniques used for advertising and posters ("low info density") with those from Tufte for statistics, maps, and other "high info density" data representations. Also has a rich display of book cover publishing trends and issues.

McCloud, Scott. Understanding Comics. Northhampton, MA: Kitchen Sink Press, Inc., 1993.
Fascinating study of what a comic is, done in the comic medium. McCloud explores the history of comics, moves on to notions of time and implied action, and develops a conceptual model to represent what he calls "Pictorial Vocabulary", with three dimensions labeled the picture plain, reality, and meaning/language. Discusses with equal facility semiotics, semantics, practice, and social uses of comics, all the while managing to entertain. Sets a standard within its field.

Mirzoeff, Nicholas, Ed. The Visual Culture Reader. London: Routledge, 1998.
A highly theoretical, academic study of what it means to observe things, using various levels and lenses of analysis such as feminism, postmodernism, and cultural studies. Includes an essay on Maya Lin's Vietnam memorial. Good for background reading on how and what we choose to see.

Mok, Clement. Designing Business: Multiple Media, Multiple Disciplines. San Jose: Adobe Press, 1996.
Mok looks at the intersection of Web page creation and regular principles of visual design. He breaks his book into three main categories: identity design, information design, and interactivity design. Thus, this book builds from a form follows function model. Mok creates useful definitions for information architecture. Very useful case studies of information architecture and branding information are included,

but unfortunately they are all commercial and relatively large scale in nature. Includes a cd-rom with that has more information on the case studies.

Pedersen, B. Martin, Ed. Graphis Poster 91: The International Annual of Poster Art. Zurich: Graphis Press Corp., 1991.
Compare with Lupton. Focused much more on poster art with less emphasis on other forms. It also highlights just one year rather than a period like Lupton does, so there is no chance to see design evolve longitudinally.

Quintillian. Institutio Oratoria. Trans. H.E. Butler. Cambridge, MA: Harvard University Press, 1979.
Quintillian builds on his predecessor Cicero and discusses public speaking as well as how learning takes place.

Sebeock, Thomas A. A Sign is Just a Sign. Bloomington, IN: Indiana University Press, 1991.
Semiotics. Extremely theoretical considerations of what images and iconographic representations encode.

Shneiderman, Ben. Designing the User Interface: Strategies for Effective Human-Computer Interaction. 3rd Ed. Reading, MA: Addison-Wesley, 1998.
Intended for designers, managers, and evaluators of interactive systems. Reads like a textbook. Very focused on how to actually create interfaces. More technically oriented than other books of its type. Chapter 15, "Information Search and Visualization" is especially relevant and includes some wonderful color plates that highlight the possible varieties of visual displays.

Stephens, Mitchell. The Rise of the Image, the Fall of the Word. New York: Oxford University Press, 1998.
Argues that visual images and electronic communications are not inferior to the written word. Mostly focused on film and television, it does discuss the Internet briefly.

Stephenson, Neal. Snow Crash. New York: Bantam, 1992.
Science fiction novel that includes a very full description of a virtual library and how it could be used.

Stephenson, Neal. The Diamond Age, or, A Young Lady's Illustrated Primer. New York: Bantam, 1995.
Science fiction novel about how and what a young street urchin learns from an extremely interactive graphical device and the consequences that result.

Tufte, Edward. Envisioning Information. Cheshire, CN: Graphics Press, 1990.
A wonderful book that focuses on how to display complex sets of information. In particular Tufte examines techniques that make the relationships among multivariable data more clear on the two-dimensional world of paper or a computer screen.

Tufte, Edward. Visual Information: Images and Quantities, Evidence and Narrative. Cheshire, CN: Graphics Press, 1997.
Tufte shifts his focus towards using pictures as explanations or verbs and argues that having good data or information presented visually is meaningless unless the intended message can be easily understood. Like his earlier work this book is utterly beautiful to look at and read. Tufte continues to urge for clarity in all aspects of visual design and begins to way in on computer screen presentations, though this subject is only a small part of the book.

Tufte, Edward. The Quantitative Display of Information. Cheshire, CN: Graphics Press, 1983.
The first book of his celebrated trilogy. Tufte begins his exploration of visual design by examining ways of presenting numerical data (especially statistics) in easy to read formats. Not as wide ranging as the follow-ups, but the groundwork is laid.

Wainer, Howard. Visual Revelations: Graphical Tales of Fate and Deception from Napoleon Bonaparte to Ross Perot. New York: Copernicus (Springer-Verlag), 1997.
Much in the style of Edward Tufte. Wainer actually uses some of the same examples as Tufte. He focuses, however, on graphs and their misuses and possible limitations rather than going more broadly into visual design like Tufte does. Very useful for considering how libraries display statistical data.

Wood, Denis. The Power of Maps. New York: The Guilford Press, 1992.
Excellent treatment of maps as visual design and expository statements. Part of the Mappings: Society / Theory / Space series, a title which describes quite well what the idea of visual design and information architecture is all about.

Woolsey, Kristina Hooper. VizAbility: Change the Way You See the World. Boston: PWS Publishing Co., 1996.
An exemplary tool for visual design and information architecture. One section focuses on sketching ideas and developing concept maps. Includes a book that discusses visual thinking and communication. Also has an interactive cd-rom and a sketch book to practice visual design.

Yates, Frances A. The Art of Memory. Chicago: University of Chicago Press, 1966.
An extremely dense, unusual, and fascinating study of hermetic philosophy and its influence on how people used spatial techniques to remember prodigious amounts of information.

Articles

Brooks, Martin and Jennifer Campbell. "Interactive Graphical Queries for Bibliographic Search." *Journal*

of the American Society for Information Science. 50(9):814–825, July 1999.
Discusses "islands", an interactive visual display for database searches. A very intuitive means for displaying the sizes of and relationships among the sets that are created through Boolean searches.

Bruza, P.D. and D.W. Song, and K.F. Wong. "Aboutness from a Commonsense Perspective." *Journal of the American Society for Information Science*. 51(12):1090–1105, October 2000.
Somewhat different than most of the other articles in this bibliography; this article discusses how systems decide on whether a document is about a query. I thought it might be useful to consider how this is done, before thinking about how to visually display "aboutness". A very difficult article to read, requiring knowledge of logic and mathematics.

Chen, Chaomei. " Individual Differences in a Spatial-Semantic Virtual Environment." *Journal of the American Society for Information Science*. 51(6):529–542, April 2000.
Presents statistics about correlation between spatial ability and associative and visual memory. No significant effects were noted for spatial ability and associative memory. Chen concludes that the interplay between subjects' mental models and real world searching experience is complex.

Chen, Chaomei, et al. "Individual Differences in Virtual Environments-Introduction and Overview." *Journal of the American Society for Information Science*. 51(6):499–507, April 2000.
This article presents a brief historical overview of individual differences in the context of virtual environments. Focus is placed on how users approach visual technology.

Dillon, Andrew. "Spatial-Semantics: How Users Derive Shape from Information Space." *Journal of the American Society for Information Science*. 51(6):521–528. April 2000.
Dillon argues that too much emphasis is placed on designing the best possible navigational aids for a given visual system. He argues that more attention should be paid to how individual users make semantic sense of the information space they create.

Ford, Nigel. "Cognitive Styles and Virtual Environments." *Journal of the American Society for Information Science*. 51(6):543–557, April 2000.
Researches how different cognitive approaches to learning by individuals shapes the choice of navigational path and tool use.

Gullikson, Shelly et al. "The Impact of Information Architecture on Academic Web Site Usability." *The Electronic Library*.17(5): 293–304, October, 1999.
Looks at how faculty access and use information systems. Gullikson assesses how information is categorized, labeled and presented, and how navigation is managed. Gullikson concludes that information architecture is designed too much around "look and feel" rather than information. Makes very specific and helpful recommendations for information architecture for academic libraries.

Lunin, Lois, and Mark E. Rorvig, Eds. "Perspectives on … Visual Information Retrieval Interfaces: Introduction and Overview: Visualization, Retrieval, and Knowledge." *Journal of the American Society for Information Science*. 50(9):790–793, July 1999.
Summarizes the contents of a special issue dealing with visual information retrieval interfaces. The issue presents exemplary types of visual interfaces and displays.

Marshall, Catherine C. and Frank M. Shipman III. "Spatial Hypertext: Designing for Change." *Association for Computing Machinery. Communications of the ACM*. 38(8): 88–103, August 1995.
Focuses on information architecture and how it has grown more sophisticated, expressive, and flexible by using spatial models rather than traditional hypertext models.

Poincot, Phillipe. "Maps of Information Spaces: Assessments from Astronomy." *Journal of the American Society for Information Science*. 51(12):1081–1089, October 2000.
An example of how a visual information display was implemented to show bibliographic and other relevant information relating to astronomy journals.

Ramsey, Marshall, et al. "A Collection of Visual Thesauri for Browsing Large Collections of Geographic Images." *Journal of the American Society for Information Science*. 50(9):826–834. July 1999.
Provides examples of visual thesauri and argues that machine methods of generating searchable indexes for digital image collections are viable, due to the overwhelming task that prevents human indexing of such collections.

Rorvig, M.E. et al. "The NASA Image Collection Visual Thesaurus." *Journal of the American Society for Information Science*. 50(9):794–798. July 1999.
Describes the first proposal for visual tools in an indexing environment. It is an unpublished manuscript from 1988 and thus of historical value.

Rorvig, Martin and Matthias Hemmje. "Conference Notes – 1996. Foundations of Advanced Information Visualization for Visual Information (Retrieval) Systems." *Journal of the American Society for Information Science*. 50(9):835–837. July 1999.
Presents a list of tasks that any visual information retrieval system should be able to accomplish if it is to be robust and adaptable for individual users.

Small, Henry. "Visualizing Science by Citation Mapping." *Journal of the American Society for Information Science*. 50(9):799–813. July 1999.

Describes systems to arrange and display citation mapping information in a visual and spatial manner.

Trumbo, Jean. "Describing Multimedia: The Use of Spatial Metaphors and the Design of Multimedia." *Visual Communication Quarterly*. Spring, 1998, 7–10.
Argues persuasively that spatial metaphors are apt and powerful ways of understanding how multimedia are used and thus should be considered in their design.

Trumbo, Jean. "The Spatial Environment in Multimedia Design: Physical, Conceptual, Perceptual, and Behavioral Aspects of Design Space." *Design Issues*: 13(3):19–28, Autumn 1997.
Trumbo claims that multimedia activities can be described by three-dimensional forms and that the processes of orientation and navigation have parallels to regular 3D space. Trumbo has a very interesting idea that sculptural space, space meant to be observed, rather than inhabited, is expressive in nature; it has an emotional, artistic component.

Trumbo, Jean. "Spatial Memory and Design: A Conceptual Approach to the Creation of Navigable Space in Multimedia Design." *Interactions*. 5(4a): 26–34, July / August 1998.
Includes a model that shows how memory interacts with and helps create spatial navigation metaphors for users using visual displays.

Withers, Rob, et al. "Information Architecture: Tools for Cutting-edge Web Developers." *College and Research Libraries News*. 61(9): 784–787, October 2000.
Offers a variety of resources, including organizations, listservs, and websites dedicated to information architecture and how it can best be applied in an academic library setting. Annotated.

Web Sites

Creating Usable Websites – Edward R. Tufte Page. 10 October 2000. http://www.tekdok.com/usablewebsites/tufte.htm.
Lauds Tufte for his design work. Includes a lot of examples for making good web sites and links to other articles on the same topics, including Tufte.

"The Data Artist." *Salon* 10 March 1997. 10 October 2000. http://www.salon.com/march97/tufte2970310.html.
Accurate summaries of Tufte's three famous books. Highlights his principles of design while critiquing his tendency to repeat information from book to book. Also defends his stance on web design from charges of Ludditism.

Trumbo, Jean. Visual Communication Bibliography Page. September, 1998. Department of Agricultural Journalism, University of Wisconsin-Madison. 10 October 2000. http://www.wisc.edu/agjourn/trumbo/biblio.html.
Huge and comprehensive listing of books on a variety of topics that connect to visual communication. Divided into twenty-three topics including (to show the variety) cartoons, caricature, and animation, semiotics, and ethics of visual communication. The bibliography is eighteen pages long and probably represents the work of a career. Not annotated.

Trumbo, Jean. Web Design Guide Page. August, 1999. Department of Agricultural Journalism, University of Wisconsin-Madison. 10 October 2000. http://www.wisc.edu/agjourn/trumbo/webgraph.
Nicely designed and very usable site that breaks creating web pages into sequential activities. The layout of this page reflects her ordered list of activities. Not just a list of technical specifications, her design activities include mission statement, content planning, usability testing, and managing the site as well as topics like navigation design, and production.

Tufte, Edward. Home Page. 8 October 2000. http://www.cs.yale.edu/people/faculty/tuftle.html.
Extraordinarily sparse home page with just a brief biographical sketch and limited bibliography.

Webmonkey Home Page. 20 October 2000. http://hotwired.lycos.com/webmonkey/.
A large site with lots of tutorials on web page and site design. Includes articles of interest to information architects.