Revolutions and Images and the Development of Knowledge: Implications for Research Libraries and Publishers of Scholarly Communications

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Volume 7, Issue 3: Models, April, 2002
DOI: http://dx.doi.org/10.3998/3336451.0007.303
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Over a decade ago Steve Harnad posited a fourth revolution in the means of the production and dissemination of knowledge. Most would agree that we are today in the midst of this revolution; many would highlight the speed of and ease of access to information as chief markers of this revolution. But revolution is unsettling. Close and Bridge say that revolution "destroys people's security and unsettles their convictions" — feelings that many librarians and publishers have today.

As a historian, albeit one who was trained in studying the artifacts rather than the writings of man, I am always interested in the historical context within which activities and actions are placed. Elizabeth Eisenstein's book on the Gutenberg revolution first exposed me to interesting parallels between the third and fourth revolutions, and, as a result, I have begun to look at these two revolutions by focusing specifically on the role of images.

Three interesting comparisons have emerged. First, the third revolution introduced exact repeatability, critical to the dissemination of knowledge. Yet, while digital imaging technology has made exact repeatability effortless in the fourth revolution, that technology has opened the door to continual changes to images, bringing into question provability and demonstration of exact repetition. Second, a major component of the third revolution was fixing reality, especially in the scientific world. Today we are about multiple and changing realities. Finally, the third revolution created a linear fixity, specifically with relationship to the alphabet and the nature of argument and discourse. Today, computer capabilities afford us the opportunity to represent the nonlinearity of human experience, and, as we do so, we will further change the nature of how we think.

This paper briefly considers images in the third revolution, images today, and the potential for the representation of nonlinearity and three- and four-dimensionality to affect the production of knowledge. Closely tied to this are the changing patterns on how information is assimilated and how all of these will irrevocably change the business of information professionals. The conclusions I draw suggest that, despite the advantages of ease of access, rapid dissemination, and immediate feedback offered by the capabilities available in the current revolution, it is in the capability of representing two things — the three- and four-dimensionality of the human experience and the nonlinearity of ideas as they happen rather than as they are written — that we will see the most startling aspect of this revolution in the production and dissemination of knowledge.

As we stand at the beginning of this revolution, it is useful to consider the most recent completed revolution
and the parallels and dissimilarities to what we see today. As a starting point for this consideration, Elizabeth Eisenstein's work, *The Printing Press as an Agent of Change*, offers much of value. There are good reasons for considering possible parallels between changes during and after the introduction of print and during this time of the introduction and growth of digital communication and the Internet:

- First and foremost, similarities and dissimilarities offer insight into the validity of the hypothesis that digital capabilities and the Internet represent the fourth major communications revolution.
- Second, consideration of these earlier parallel and related phenomena may help us place the current ones in a broader perspective. With the passage of 500 years, it is clear that the scribal culture gave way completely to print culture. It is, however, far too early to say that print culture will give way to or be absorbed by or even significantly changed by Internet culture.
- Finally, and of specific interest here, consideration of the changes in textual communication helps evaluate changes in graphic communication. Graphic and symbolic communication long preceded written communication and yet, while the effectiveness of written communication increased enormously with the advent of printing, digital capabilities may well make graphic communication a paramount means of communication in this global age. At the least, digital graphic capabilities, I suggest, may be the heart of the fourth revolution in the production and dissemination of knowledge.

**Images as a Mode of Communication**

Man has created images since the early days of human existence. Traces of some of the earliest have been found painted on caves walls and carved on bone; later ones appear on pottery before writing came into existence. Unless these images were attempts to represent an object in as natural a fashion as possible (e.g., bison, deer), many of the images, in the absence of written language, can only be assumed to have functioned symbolically — symbols we are at a loss to interpret definitively today. Even after writing allowed people to communicate ideas among themselves outside of spoken language, descriptive images were often required to either explicate the ideas or substitute for them among the non-literate population.

Georgius Agricola, writing about "the veins, tools, vessels, sluices, machines, furnaces," in *De Re Metallica*, published in 1556, indicated in his preface that he "not only described them, but . . . also hired illustrators to delineate their forms, lest descriptions which are conveyed by words should either not be understood by the men of our times or should cause difficulty to posterity." Although antiquity produced significant illustrations, including herbals, diagrams, and ancient maps, until there was the ability to produce exactly repeatable images, reliance on pictures was not possible. As William Ivins points out, the surviving texts of Ptolemy, Vitruvius, Pliny, and others, transmitted without pictures to accompany the often copied and translated words, were difficult to understand (468). Vitruvius, for example, refers to diagrams and drawings that had become detached from the texts after the tenth century, rendering the texts far less meaningful. Curt Buhler, in his work on fifteenth century scribes, writes that:

> When used as a visual aid, however, the picture represents something controllable, necessary, and comparable. To us (as to medieval man, even with his imperfect grasp of the fundamentals) representations of anatomical figures, herbs, animals, views of cities, astronomical configurations, maps, instruments of war, and other familiar or recognizable portrayals complement the written word and are essential to it, whether the volume be a manuscript or a printed text. Botanical treatises and geographical works without explanatory pictures are quite meaningless and incomprehensible. (Buhler 71)

Botany, anatomy, and map-making came into their own as disciplines only when exactly repeatable images became available. Until then, the information lost in repeated copying (by different hands) rendered illustrations far from perfect if not useless for the transmission of knowledge. Ivins attaches great importance to the image as a means of communication and as a distinct part of the development of knowledge, suggesting that

> [t]he only knowledges in which the Greeks made great advances were geometry and astronomy, for the first of which words amply suffice, and for the second of which every clear night provides the necessary invariant image to all the world. . . . All kinds of reasons have been
The development of the exactly repeatable image occurred in the early fifteenth century although the technical capabilities had long been present (e.g., striking of coins, seal and metal engraving, goldsmithing techniques). It preceded the development of movable type by a half-century but only became a true medium of transference of knowledge when placed in conjunction with the printed book.

Before the engraved image, the inability to exactly reproduce an image by hand copying was further exacerbated by both intentional and unintentional changes introduced by the copyist. After the introduction of wood-engraved images, the cumulative degradation of the images reproduced by repeated printing sets them apart from text as well. Although far superior to those produced by hand copying, the images created by worn-down or refreshed plates provide less value as a descriptive medium than the original. (Text may be faint or corrupted with use of worn type blocks — even missing words and phrases, but the meaning generally can be read or inferred.)

In considering the communicative value of illustrations in printed material, Williams Ivins suggests that this field in the study of early printed books may be fertile ground for research:

[I]t was not until long after printed pictures were in common use that recognition of the social, economic, and scientific importance of the exact repetition of pictorial statements did not come about until long after printed pictures were in common use. . . . The historians have concentrated their interest on some technicalities in the printing of the book and on the identity of the designer of the woodcuts, but they have unanimously overlooked the importance of these illustrations as the first set of illustrations made definitely for informational purposes. (16, 31-32)

Ivins vividly makes clear the importance of exact verbal repeatability; his words apply equally to visual repeatability. Ivins writes:

A definition or description that cannot be exactly repeated is not only of little use but it introduces extraordinary complications and distortions. If it had been impossible to repeat exactly a verbal formula there would have been no law, no science, no religion, no philosophy, and only the most rudimentary animal technology. (62)

Edward R. Tufte, whose three books on information design demonstrate the criticality of images not only to convey information but also to create knowledge, provides an eloquent example of the power of graphics. Dr. John Snow plotted the location of deaths by cholera in central London in September 1854 (1983: 24). Deaths were marked on a map by dots and, in addition, the area's eleven water pumps were located by crosses. It was the presence of one of these pumps, the Broad Street water pump, which showed that cholera occurred almost entirely among those who lived near or drank from this pump. While this coincidence may have been seen in lists of figures eventually, it is clear how much more quickly it was made obvious by the graphic of a simple plot.

Images Before and in the Third Revolution

Exactly repeatable images did not begin with books produced with movable type. Nor did they begin afterwards as a necessary development. Rather, sometime in the early 15th century, exactly repeatable images began in the crude prints, representing scenes from the Scriptures and the lives of the saints, scattered across Northern Europe and produced by wood-engraving or wood-cuts. They were not produced as part of bound volumes but on single leaves of paper. In fact the earliest documented use of wood-engraving was a new industry — the production of playing cards — which, as George Woodberry describes,
Digital media are both more temporary and more permanent than analog media

Although it has long been a misconception that the block-books preceded and inspired books from movable type, their history, in fact, coincides much more with that of the early books produced from movable type (Pollard). It is true, however, that text in the block-book was subsidiary to the image while in the printed book, the image was most frequently subsidiary to text. The printed, illustrated book was the product of typography and wood-engraving (soon to give way to copperplate-engraving). Woodberry discusses the early illustrations and argues that the need for inexpensive and rapid processes degraded what art there was in the illustrations. He makes an interesting point about the different use of illustrations in Latin and vernacular texts:

The illustrations in the new books had ordinarily little art-value: they were often grotesque, stiff, ignorant in design and careless or inexpert in execution; but they had nevertheless their use and interest .... The books in Latin, the learned tongue, were usually without woodcuts; but those in the vulgar tongues, then becoming the true languages, the development and fixing of which are one of the great debts of the modern world to printing, were copiously illustrated, in order to make them attractive to the popular tastes. (27, 48-9)

The first books produced show that printers replaced scribes and only scribes; they were still dependent on the illustrator for illumination, printed head-titles, initial letters, chapter headings, etc. We know this from the number of early books that have come down to us in what appears to be the exact state in which they issued from the press: with blank spaces at their beginning for illumination, blanks for initial letters, and so forth. These were to have been completed by illuminators or rubricators.

In the first few decades of print, the illustrated book developed quickly. Between Belon's Natural History of Birds (with its precise illustrations) in 1455, to Albrecht Durer's Apocalypse in 1498 (considered by many to be the greatest illustrated book of the fifteenth century), numerous works illustrating subjects as diverse as botany, zoology, astronomy, military machinery, travel, and medicine were published to describe scientific and factual information. A list of major illustrated works of the first few decades indicates how quickly the illustrated book developed, especially to describe and illustrate scientific and factual information.

The importance of the exactly repeatable illustration in the enormous scientific advances which were to come is clear. Early books — and some even earlier manuscripts — occasionally contained moving parts, used either for instruction or actual calculation. In 1474, Regiomontanus produced in Nuremberg his Calendarium, which contained two instruments with moving parts. One had a jointed brass pointer, while the other was a simple lunar calculator with two moving circles or volvelles. (Gingerich: 288). These moving-part books preceded Galileo's Jovibabes, nomogram-like computation devices that recounted orbits of Jupiter's satellites (Tuft 1990:99) and hint of the three-dimensional models available online today.

Philip Hofer, in an essay on the early illustrated book, places the influence of the illustration alongside education itself:

The growth of universities and increasing literacy caused an unexpectedly heavy demand for books. Illustration greatly widened the comprehension of the text for those who read slowly; in fact, pictures plus text gave the book two dimensions, each supplementing the other. (277)
Images in the Fourth Revolution

Graphic images, specifically, the exactly repeatable image, had a critical role in the blossoming of scientific discoveries that began in the fifteenth century, and I am convinced that the digital image will play an equal if not more critical role in this fourth revolution of knowledge development and dissemination. But what is it about a digital image that will effect such a role?

The Nature of Digital Images

The digital image is simply a set of numbers read and inscribed fresh each time an image is presented, whatever the medium; it is a numerical file for which the concepts of original and copy are useless or at best inadequate. Critically, the specific appearance of a digital image depends entirely on both the output method that converts the numbers and the analog medium on which it is ultimately presented. As Timothy Binkley asks and answers:

Which one is the digital image? Both and neither. The numbers function as the foundation of a visual construct, but they do not completely dictate its appearance. (112)

And files of digital images are routinely transmitted for display on machines over which the image's creator has no control. The digital image, Binkley suggests, while intangible and invisible, is perceived through an interface that changes the numbers into a visual presentation, a process that enhances our ability to visualize and that affects science as well as art. This process weakens the barriers as art "gets imbued with numbers and our science gets advanced by art."(115) Binkley discusses the idea of reality and suggests that "our sense of reality is determined in large measure by our scope of representations" (115). He quotes Ian Hacking on this point:

Reality is an anthropomorphic creation. Reality may be a human creation, but it is not a toy; on the contrary it is the second of human creations. The first peculiarly human invention is representation. Once there is a practice of representing, a second-order concept follows in train. This is the concept of reality, a concept which has content only when there are first-order representations. (136)

Against this introduction to the intertwining of science and art we can place Patricia Search's discussion of "The Semiotics of the Digital Image." Here, she points out that mathematicians and physicists have shown us that our perceptions are not necessarily accurate reflections of reality. Examples she presents include the work of the nineteenth century German mathematician Riemann who postulated that space could be curved — a theory Einstein used to develop relativity. With Riemann's theory and new methods of defining and visualizing spatial-temporal concepts, "the linear determinism of Euclidean geometry was slowly replaced by mathematical models that described multidimensional, abstract relationships" (312). Search also refers to classical physics in which "reality was an objective truth and the scientist was a passive observer looking on. "With the introduction of relativity and quantum physics, a new scientific model of the world emerged in which dynamic interactions replaced static, linear forces" (312).

Search suggests that "artists, mathematicians and scientists are no longer concerned with a single view or interpretation of reality. Instead, the emphasis is on using digital technology to modify perspectives and restructure information" (317). The modification of perspectives and restructuring of information have made it possible for scientists and artists to construct new knowledge beyond the existing boundaries of logic and expectations. The "reality" of digital images creates new realities previously inconceivable. Today this new knowledge rarely exists within fixed boundaries of individual disciplines; rather it exists without any specific disciplinary limits or location. What precedes the creation of new knowledge is
another level of abstract thinking called visual logic. However, unlike writing, which separates data from interpretation, this new abstract symbolism uses visual perception to synthesize data and interpretation into an integrated whole. (Search: 315)

There are a few striking differences between analog and digital images, differences which will greatly influence the production of knowledge:

- The traditional image is focused on concrete preservation and presentation, both functions coalescing in the material substance of the medium; the new, digital image is focused on abstract storage and manipulation, each function relatively independent of the other.
- Although digital technologies can be excellent mimics of analog ones, their functionality is far more diverse.
- Analog medium is grounded in a specific material where images are transcribed from one substance to another while digital images convert information from material into numerical entities. Or, in the words of Hartman, "A painting is a manipulation by the artist of physical materials such as paint on a layer. The new media — starting with photography — are in essence capturing the light. They are in fact non-substantial."
- Digital media are both more temporary and more permanent than analog media. They are more temporary because they require transient technology to convert and display the image, more permanent because once the image is stored as numeric data in computer memory, it can be processed in unlimited ways without degradation of information.

William Vaughan argues that there are three great advantages to the digital image: stability, transferability, and manipulability. Stability and transferability allow reproductions that are both more accurate and less susceptible to decay, with innumerable copies made without any loss of quality. Manipulability means to Vaughan that individual features of an image can be isolated and analyzed, offering a real advantage in medical research, for example, where abnormalities can be more readily detected.

Vaughan may see reproducibility as an advantage of digital images, but not all of us would agree. Reproducibility or multiple copies of the same image first became possible before the Gutenberg Revolution as illustrations were created and produced by wood engraving. The concept of original versus reproduction did not really enter the discussions at this time although the deterioration shown by the repeated issues of a print (i.e., "copies" was clearly a factor in evaluating how far a print was from the first engraving. It was with photography that the discussion of original versus reproduction began and that discussion continues in earnest now as we confront the "original" digital image and any number of possible "reproductions" on any number of media: paper, cloth, computer screen, etc. Here — even more than with photography — the possibilities of easily modifying the original artist's intent confuses the discussion.

The digital work of art is "physically and formally a chameleon . . . [without] a clear conceptual distinction between original and reproduction (Davis: 381). One of the clear distinctions we must make today, in fact, is that works of art in traditional (non-digital media) are defined by their uniqueness, while digital media may be defined by their truly exact reproducibility. The concepts of uniqueness and reproducibility appeared in Walter Benjamin's essay "The Work of Art in the Age of Mechanical Reproduction." Benjamin equates uniqueness with manual production and reproducibility with the mechanical (re)production of art. Although Benjamin saw some implications of mechanical reproduction in which the original would be devalued to meaninglessness — a logical conclusion in the time he wrote — we see today that this has not happened. Douglas Davis relates that

what begins to emerge in the first digital decade is a fine-grained sensitivity to the unique qualities of every copy, including the digitally processed photograph . . . . Here is where the aura resides — not in the thing itself but in the originality of the moment when we see, hear, read, repeat, revise. (385-86)

What remains a legitimate concern today is not reproducibility but the specter of easy and undetected modification of an image. From the perspective of the art world this may be interpreted as the creation of a new work of art and, indeed, Ansel Adams left his silver-based negatives to an American university just so
that others could create new works from the originals. Adams likened the making of a negative to the writing of a musical score, and the printing of it to the performance of the music which can be interpreted in a number of different ways by different orchestras and conductors. (Campeanu: 79)

From the perspective of the academic community, however, the possibilities of undetected modification of an image will cast a heavy shadow over the unfettered use of the Internet for communicating the results of scientific inquiry. George Legrady, referring to digital images, suggests that

given the very high probability that digital filtering of one sort or another could have been used in the transmission process, prior knowledge about an image's history - its source, its mode of production and reproduction — have become necessary informational components to understand accurately its full meaning [as intended by the originator]. (266)

Tufte, writing about graphical evidence in general, is more specific; this specificity makes clear the difficulties we will face in attempting to provide a full history of an image. Tufte writes:

How are we to assess the integrity of visual evidence? What ethical standards are to be observed in the production of such images? One way to enforce some such standard of truth-telling is to insist that the innocent, unprocessed, natural image be shown along with the manipulated image, and, further, that the manipulators and their methods be identified. If images are to be credible, their source and history must be documented. And, if an image is to serve as serious evidence, a more rigorous accounting should reveal the overall pool of images from which the displayed image was selected. (1997: 25)

Bearman and Trent discuss the issue of the authenticity of primary source material in digital format within the research process. Their discussion can easily be extended to digital images created as part of the research process. After reviewing the criticality of authenticity to various stages of the research process (information discovery, retrieval, and use) and presenting some solutions, they conclude:

Many technical methods are being developed or offered that purport to address the issues of authenticity and integrity of information resources. To determine which methods are suited for what purposes, it is critical that we better understand the functional requirements for authenticity on the part of creators and potential users of digital resources, and appreciate where in the research process these requirements come into play. (9)

All of the above seriously increases the complexity of the job of the information professional.

Images and New Worlds

Steven Holtzman's interest in using computers echoes the thoughts of many artists and scientists working in cyberspace:

To me the most exciting aspect of using computers as creative partners is the possibility of creating completely new worlds, unthinkable before computers. Although software systems can be used to create instrumental music, painting, and other predigital art forms, we were expressing ourselves in those forms long before the computer existed. Obviously, it's possible to compose music and to paint without the computer as a creative partner. However, it isn't possible to create a complex digital world. The complexity of the virtual world requires that a computer be programmed as a tool to create it. Exploring fractals and artificial life necessitates collaboration with a computer as a creative partner. (1998: 77)
Robert Root-Bernstein, in describing the importance of visual thinking and creativity in the scientific process in 1980s, highlights the close connection between the arts and the sciences and the level of importance attached to nonverbal forms of thought by "most eminent scientists." He discusses the work of a number of scientists who reported the use of "mental visualization," "visualized mental models," or even "mental games." He writes:

"The most influential scientists have always nonverbally imagined a simple, new reality before they have proven its existence through complex logic or produced evidence through complicated experiments. . . . [T]his ability to imagine new realities is correlated with what are traditionally thought to be nonscientific skills — skills such as playing, modeling, proximating, extrapolating, and imagining the as yet unseen — in short, skills usually associated with the arts, music, and literature (61)."

He continues to discuss formal, verbal logic — a product, it has been said, of the written word —

"bounded by internal constraints that make it incapable of fruitfully addressing noninductive and nondeductive processes such as modeling, abstracting, harmonizing, pattern forming, approximating, and imaging the yet unseen. . . . In other words, creativity may require the ability to transform one form of experience (e.g., a mathematical problem) into another form (e.g., visual) and then be able to translate the resulting idea into a communication form (be it a drawing, music, or words). (62-63)"

Just more than ten years ago, Tufte lamented the lack of ability to readily represent the complex world described by Holtzman and the visualized models of Root-Bernstein. His work addresses what he calls "flatland" where four dimensions — three of space and one of time — must be portrayed on our information displays . . . caught up in the two-dimensionality of the endless flatlands of paper and video screen. . . . Escaping this flatland must be the essential task of envisioning information — for all the interesting worlds (physical, biological, imaginary, human) that we seek to understand are inevitably and happily multivariate in nature. Not flatlands. (1990:12)

It is precisely in the ability to portray the full four dimensions, I am convinced, that the graphic capabilities of the fourth revolution will have a major role in knowledge creation and dissemination. A number of disciplines can only truly communicate through three- or four-dimensional models and realities. I choose to skip my own field of archaeology, which so obviously depends on the three dimensions of space and the fourth of time, and turn instead to molecular modeling.

Henry S. Rzepa offers some insights illuminating these points from chemistry, where the image is as important a part of the information exchange as the text. What he describes holds in related fashion for other disciplines. Rzepa has indicated that he has "become interested in how the rapidly evolving Internet can function as a key enabling tool for chemistry, the dissemination of the subject, and a method of promoting interdisciplinary interactions with other subjects." And, in a series of articles, he describes the development of molecular modeling from the 1970s to the present and comments on the future possibilities. In an e-mail message to me, Dr. Rzepa confirmed the use of images by chemists:

"Since around 1880, chemists have "imagined" their subject in three dimensions, and several Nobel prizes have been awarded for this aspect (including the first!)."
and behaviors of molecules. Representation of the molecules has progressed from the 1970s when they were represented by lists of atomic numbers, bond lengths, and angles, plus connectivity information, and access was via teletypewriter and modem to a mainframe — “hardly the most intuitive way of showing their shapes and properties (Rzepa 1996)” — to the 1980s when chemists exchanged computer files using point-to-point connections to remote resources (although it was still necessary to have considerable expertise in using a text-editor to extract and reformulate the information in the files for local processing).

Rzepa shows this in an illustration in one of his articles. In print, there is a figure of a specific concept. Using free Chime software that you can download from the Internet, you can inspect and manipulate an interactive three-dimensional model. View (after downloading Chime) for example, the molecule at http://www.ch.ic.ac.uk/local/organic/halo.pdb. Or go to Molecule of the Day [formerly http://www.wellesley.edu/Chemistry/chem120/12000moleculeofday.html] or Molecule of the Month.

We have moved a long way from lists of atomic numbers in the 1970s to a three-dimensional model of the molecule, a difference as stark as that between Ptolemy's list of coordinates provided in his Geographica, and the actual maps — whose contemporaneity has been argued for some time and the discussion of which underscores the critical need for exact image replication. The moving molecule reminds us as well of the books with movable parts. Given the development from lists of atomic numbers to 3-D molecular models, it is not surprising that the discipline of chemistry has already presented a number of opportunities for multimedia publication (Journal of Molecular Modeling, Internet Journal of Chemistry [formerly http://www.ijc.com/ ; archived at http://web.archive.org/web/20070423154412/http://www.ijc.com/].

Alas, although there are well over two million chemical documents available via the Internet (according to Rzepa), it is hard to determine how many actually carry meta-information, alternative chemical fields or links to models, since the current generation of search engines is not programmed to search for such information. (Nor are they programmed to search for images unless specifically developed for this purpose and then, only with limited capabilities.) This accentuates some of the challenges facing libraries or publishers today.

The use of visual perceptions to synthesize data and interpretation in one unified model provides enormous potential for information exchange as clearly as the introduction of exact repeatability did in the fifteenth century. The illustration of molecular modeling alone suggests how the development of digital images and free exchange via the Internet now transform and create new knowledge.

Linearity

I noted above the linear fixity of the earlier revolution. Robert Root-Bernstein describes “visual thinking,” differentiating it from “verbal thinking [which is linear, whereas experience of most kinds is nonlinear and concomitant.” (58) Holtzman, on the subject of the linearity of print and its derivation from the linearity of the alphabet, writes that “[i]n sharp contrast to the alphabet, the nature of digital technology is random access. It's nonlinear.”(1998:172) In fact, one characteristic of digital media is their ability to access one random point and then jump to another. Because of this, Holtzman suggests that:

Ultimately, the computer and new media will reshape the very ways we think, just as the linear nature of the alphabet has shaped our thinking and influenced our intellectual world for thousands of years. (Holtzman 1998:172)

The implications of this for the library and publishers, whose very organizations are owed to the linearity of the alphabet, are enormous. How can publishers produce and promote, and libraries store, information that does not fit into neat packages called books or journals? How can publishers promote, and libraries catalog, pictures that are represented by their traditional thousand words? How can these two entities, developed over centuries and bound by their very nature to formal, verbal logic, address the "noninductive and nondeductive processes such as modeling, abstracting, harmonizing, pattern forming, approximating, and imaging the yet unseen" (Root-Bernstein: 62) that is the new scholarship?

The words of Root-Bernstein and Holtzman underscore another fundamental and ultimately transforming
difference between the third and fourth revolutions, and suggest possibilities of change in our very thought processes after decades, not to mention centuries, of new media.

Although the term "hypertext" was coined in the 1960s and was followed by the term "hypermedia" in the 1970s, and although the true strengths and possibilities of non-sequential writing and hyperlinks are only beginning to be seen today, we owe to Vannevar Bush the description in the 1940s of an associative system that could store text and images in the way he believed information is linked in the human mind. In his 1945 Atlantic Monthly article, Bush wrote that the human mind operates by association. With one item in its grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain. . . . [T]he speed of action, the intricacy of trails, the detail of mental pictures, is awe-inspiring beyond all else in nature.

In order for the associative indices in our mind to work, the digital object must bring together all related components that might be connected to the main concept, not in a linear fashion but rather into "a matrix that can be freely explored" (Holtzman 1998). Are we prepared today to describe the book catalog or the library that will make these associative indices possible? Is its first incarnation the Internet as we know it at the beginning of the twenty-first century?

Holtzman suggests that a shift to nonlinearity was seen in MTV, "the first widely popular medium to exploit electronic media's ability to simultaneously present several different stories." (1998:171) It is now permeating all of our culture and soon, Holtzman predicts, we will no longer expect a beginning, a middle, and an end.

If a shift to nonlinearity is a foretaste of the new media, so too is the loss of repeatability. Earlier we discussed the criticality of exact repeatability — the ability to present information identically over and over again — in the third revolution and its place in the foundation of the rapid development of the sciences which quickly followed. Although digital images are exactly repeatable, the experience of digital works and hypermedia are not. It is precisely the lack of repeatability in much digital work, and in hypermedia specifically, that is as much a break from the past as nonlinearity is. The paradoxical outcome of this is that even if a basic property of digital technology is perfect repeatability, repeatable is exactly what nonlinear hypermedia isn't. Rather than offering a deterministic experience, digital worlds represent the possibility of creating an experience of the moment. (Holtzman 1998:189)

A decade ago, as Harnad was proposing the fourth revolution, Tufte was lamenting the ability to portray the richness of reality:

[T]he essential dilemma of narrative design — how to reduce the magnificent four-dimensional reality of time and three-space into little marks on paper flatlands. Perhaps one day high-resolution computer visualizations, which combine slightly abstracted representations along with a dynamic and animated flatland, will lighten the laborious complexity of encodings — and yet still capture some worthwhile part of the subtlety of the human itinerary. (1990:119)

Has This Day Come?

Just as the advent of the printing press introduced an era of indiscriminate publishing with a vast backlog of occult practices and formulas that turned out a great part of the initial offerings, so too today we find the World Wide Web filled with material of little or dubious value. Carter and Muir's comments on the impact of printing, with a few word changes, could easily be describing the situation today. They wrote:

Yet this multiplication of books was itself a very remarkable change. . . . Much, perhaps most, of what was printed in the centuries which followed the invention was to be of no lasting interest,
save when digested statistically: the mounting number of royal proclamations, the emergence and diffusion of the periodical press, the very numbers of the books published themselves.

(xxiii, xxix)

And, yet, just as the initial era of indiscriminate publishing changed, so will the initial era of Internet content. There were profound continuities between the first printed books and manuscript books; the electronic journal today, even when there is no print version, resembles the traditional print journal with volumes, editions, and collected papers. When will it lose the need for these ties to print-on-paper publishing? And what will happen to us who must control this material? Consider the tasks of acquisition and cataloguing material that is "published" of the moment. Or is this what the Internet already is already starting to become?

The true new media will exist only when we leave the ties to print publications and only when the special capabilities possible are routinely incorporated into all research: e.g., large databases, charts and so forth (reminiscent of early print of tables and charts), color, three- and four-dimensional models and interactive graphics, in short, all possibilities of using a distributed computing environment. And, of course, to fully use the capabilities there will need to be new tools to handle databases, software to handle Internet data, visualization and virtual reality modeling tools, pattern recognition, standards for interoperability across such publications, and a way to assure the preservation of these new media.

Creation of the experience of the moment and the inability to exactly repeat or even preserve it will change forever much of the development of and access to scholarly knowledge. The new media developing during this fourth revolution will be quite different from the static publications with which we have become accustomed, and while we can suggest components of the new media today — such as the graphic image and its permutations into three- and four-dimensional models and interactive objects — its mature form will no doubt surprise us.

I began this paper noting three critical and interrelated components of the third revolution:

- the idea of linear fixity,
- the ability to fix reality and, finally,
- the ability not only fix it but repeat it exactly.

In 2002, we see that the exact repeatability and fixing reality have given way to the currently critical ability to demonstrate multiple and changing realities and that the concept of linear fixity has given way to an ability to demonstrate the nonlinearity of human experience. I suggest that the abilities

- to represent multiple and changing realities,[11]
- to represent the nonlinearity of human experience,
- to represent "the magnificent four-dimensional reality of time and three-space," and
- to transform one form of experience (e.g., a mathematical problem) into another form (e.g., visual)

will be the most interesting and productive aspect of the fourth. With the tools available, images, models, visual representations — call them what you will — will play an even stronger role in the creation and transmission of knowledge than they did in the third revolution. These — not quantity of material nor speed nor ease of access — will be the most challenging new features that information professionals will face.[12]

Implications for Research Libraries and Publishers of Scholarly Communications

What does all this mean? What are the implications for the traditional library framework and the traditional publishers as the world of scholarly communication begins to morph to one outside the traditional publishing framework?[13] In the context of who I am — a user of information now critically interested in the preservation of and access to information, a researcher interested in the community of shared scholarship and its preservation, and a long-term administrator in higher education who is greatly interested in the place of the library in the academy and the communication of scholarship — a number of things stand out.
The concept of linear fixity has given way to an ability to demonstrate the nonlinearity of human experience. The researcher today requires the organization and structure of the research library far less than in the past — although this is strongly discipline-biased, as I’ve discovered in many casual conversations with faculty on campus. The catalog that served us so well for organizing and making print-on-paper material available may not be needed at all for digitized material with the development of ever more robust search engines. It may not be pretty to have more returns than you want, but if pure machine power alone can get you satisfactory results, then why spend inordinate human labor cataloging items? And who can imagine cataloging the Internet? [14]

Having said this, however, I add immediately that the library’s history of organizing information and making information accessible should be retrofitted to provide a new framework for access. It is the logical place for overarching structures to be developed, but today it must be the place for pro-active support of the user, rather than passive provision of self-use resources. [15]

When we consider current publishing as well as current discussions of publishing, we note that while we have firmly moved to models of electronic publication (sometimes supplementing print versions, other times as the only publication), the models — as mentioned above — almost always resemble the traditional print journal with volumes, editions, and collected papers. Excellent discussions on the future of electronic publishing are available. [16] These address the very real concerns of the economics of online publishing; production issues and typesetting; access questions (of great interest to libraries as well as individuals); intellectual property and copyright concerns; and archiving and long-term access concerns. These are issues that parallel those in the paper environment. A very recent announcement of an April 2002 seminar, "We can't go on like this: the future of journals," emphasizes similar concerns. [17] The seminar's hosts advertise that

In this seminar we examine some of the alternatives which are being proposed, ranging from new financial models to approaches which appear to bypass the publisher altogether. Our eminent speakers consider what the implications may be in the future, for the process of quality control, for the small learned society publisher, and for the learned communication process as a whole.

While the publishing industry is discussing economics, production, and access, we have a large debate in the academy about free, unfettered access to scholarship and communication of research. Paul Ginsparg’s E-Print Archive, with its more than ten-year history, is now joined by online archives in a number of disciplines and institutions across the country. This eliminates the publisher as a middleman. With the acceptance of open archive initiative (OAI) standards, we have begun to see the development of federated search engines that can cross registered online archives, enabling the researcher to readily determine what may be of interest — and this itself is a threat to functions of the traditional library.

I mentioned above the development of two online, interactive journals for chemistry. We can add the recent discussion of the Journal of Interactive Media in Education (JIME) (Shum and Sumner). In this discussion presented in First Monday, the authors ask, "How can new media positively transform scholarly practices?" While I suggest the question might be better framed as "How can the publishing medium support the dissemination of new knowledge, itself often dependent on multimedia, interactive systems?" — I concur completely with their statement that "simple dissemination is no longer an adequate model to ensure that science moves forward by building on the results of others." They call for a model that provides opportunities for "community-wide collaboration, negotiation, and knowledge construction" as well as "mechanisms to publish a wider array of intellectual products."

Despite the discussions reviewed above, the literature overall is decidedly weak on addressing just what the new methods of research and knowledge development require in the way of scholarly communication support. And when we consider the implications of a robust computing environment that models three- and four-dimensionality and encompasses nonlinearity of thought, this lack of address is disconcerting. If we
are to leave all such forms of scholarly communication to the specific efforts of individual communities (e.g.,
chemists sharing their work with other suitably outfitted chemists), then the world will be much poorer. The
publishing world and the libraries have long supported the dissemination of new scholarship and knowledge
and should not abandon their respective roles today.

Some related questions stand out.

- How are research libraries and publishers preparing for the eventuality that the change to digital access
  will result in an explosion of information and knowledge?
- How are research libraries and publishers preparing for the eventuality that nonlinear thinking or
  associative links will have a major impact on the approach to information recovery and collection?
- How are research libraries and publishers preparing for the widespread recognition that digital media
  are both more temporary (because they require transient technology to convert and display the image)
  and more permanent (because once the image is stored as numeric data in computer memory, it can be
  processed in unlimited ways without degradation of information) than analog media?
- How are research libraries and publishers preparing for the eventuality that images will be a major factor
  in this explosion of knowledge? And the corollary, that, given the very high probability that digital
  filtering of one sort or another could have been used in the transmission process, prior knowledge
  about an image's history — its source, its mode of production and reproduction — have become
  necessary informational components to understand accurately its full meaning [as intended by the
  originator]?  
- How are research libraries and publishers preparing for the recognition that, as mentioned above, even
  if a basic property of digital technology is perfect repeatability, "repeatable" is exactly what nonlinear
  hypermedia isn't?
- Who is considering the archiving implications of three- and four-dimensional online models? What are
  the implications of new versions superseding earlier versions? Are we required to retain all developing
  versions of research — with or without associated links — as part of the scholarly record? While many
  of these questions have been discussed in light of simple online text, the answers to them for these
  new models present a far more complex solution.

Particularly, we must pay attention to presenting, managing, accessing, and preserving images, including
interactive three-dimensional images. We must begin to consider what Clifford Lynch asked at the
Association of College and Research Libraries meeting in March 2001: what is fair use of a digital image? Is
it 10 percent of the image or resolution at 10 percent of the original? Or what? Since we have had a hard
time with the concept of fair use for text, we will have a much harder time with the concept for images; and
yet for researchers whose primary material may well depend on images and models, it will be critical.

For the first and second points listed above, the sheer explosion of information and information available
digitally, many initiatives are under development in research libraries and related organizations, yet some
things are missing:[18]

- Although catalogs and registers are the meat of librarians, we have yet to begin an international register
  of digitized materials. While it is wonderful to see increasing numbers of manuscripts and early books
digitized and available on the Internet, unless we have a single and coherent registry of this material that
includes the edition digitized and the quality of edition, research depending on the use of these
documents cannot flourish. When we consider how much effort is required to uniquely identify all
editions of a specific work (an act especially onerous when we address manuscripts, but even more
difficult with printed works whose problems of identity may arise due to carelessness of publishers,
editors, and authors, not to mention authorial aliases) we need think hard to recognize the problem we
will face if a systematic, standardized registry of digitized material is not soon developed.

- Although a lot of scholarship from the information science and electronic publishing communities is
  available freely on the Web, finding it is not always obvious. There are a number of fine online journals
(such as D-Lib, JEP, and First Monday) but why haven't these two groups joined forces to present an e-
print server where all material of interest in this new era of publishing scholarly communication is
available?

- Despite all the developments in libraries today, coverage of it is only slowly becoming a formal part of
  library and information science education. Despite all the developments in publishing, how many formal
publishing programs in colleges and universities today address the concerns not of publishing digitally,
but of publishing in three- and four-dimensional representations, of developing publications which are
I will close as I began. Images were far more responsible for the explosion of knowledge that began in the fifteenth century than they have been given credit. They will play a major role in the similar explosion we are undergoing today as they become tools in developing knowledge rather than simple illustrations. We need to develop standards for and ways to present, manage, access, and preserve the multidimensional, interactive images and models if we are to continue the preservation of and access to information that has been the hallmark of libraries. As a consequence of these and other developments, research libraries and publishers must be proactively involved in the changing landscape and proactively involved in defining the research library and the scholarly publication of the next generations.

Notes

1. A shorter version of this paper was presented in New York City to the Archons of Colophon, April 18, 2001.

2. A brief discussion of the similarities has appeared very recently. See Bawden and Robinson. Also see discussions in Robertson regarding the information explosions coincident with each of the four revolutions.

3. *De Re Metallica* was published a year after Agricola's death, due to the complexity of the illustrations. The following quote, from the web site of From Alchemy to Chemistry: Five Hundred Years of Rare and Interesting Books, University of Illinois at Urbana-Champaign, Rare Book Room Exhibit, makes clear his role in the history of science. The illustrations were so many, and so complicated that they delayed the final year of publication. The mining engineer Herbert Hoover (later U. S. President), who translated *De Re Metallica* into English in 1912, regarded Agricola as the...
This abbreviated list gives a good idea of the development and use of illustrations:

- In 1455, Belon's *Natural History of Birds* was published. It was of special importance to zoologists because of Belon's precise illustrations.
- In 1471, saw the publication of an edition of the *Spiegel der menschlichen Leben* by Rodericus Zamorensis, with unusually good illustrations of scenes from daily life quite different from the stolid cuts representing Scripture history.
- In 1472, there appeared at Verona an edition of Valturius's *De Re Militari*, illustrated with many large and small woodcuts representing machinery and its uses; the significance of this book lies in the illustrations of technical or scientific character which show the progressive engineering ideas of the time.
- Also in 1472, Holywood's *Sphaera Mundi* (with an illustration, presumably by Holywood, demonstrating the earth's spherical shape) was one of the first astronomy texts to be published. The manuscript had begun circulation in the early thirteenth century; it was so prized that twenty-four additional editions were published in the last three decades of the fifteenth century.
- In 1475, Conrad von Meganberg's *Buch der Natur*, the first illustrated book whose twelve plates contain a hundred plus pictures of animals and plants and attempted to inform its readers about animals, was published in folio. Although there is nothing new in the text the illustrations amount to a significant event in the history of zoological iconography.
- In 1478, *De Materia Medica* by the first century A.D. author Dioscorides, was translated from the original Greek to Latin and published. This was the first extensive pharmacopeia whose original manuscript contained no illustrations. Later authors used this text as a basis for their illustrations which appeared in this 1478 edition.
- In 1483, Leonhard Holl printed at Ulm an edition of Ptolemy's *Cosmographia*, which contains the first woodcut map.
- In 1484, the herbal known as the *Latin Herbarius*, a large and fully illustrated volume containing many woodcuts of plants, that apparently was copied from various older sources, was printed at Mainz.
- In the next year, 1485, another and completely different herbal as published in German, known as the *Gart der Gesundheit*, the first printed illustrated account of the results of a journey undertaken with scientific purposes in mind. There seems to be "no earlier statement of a writer in a scientific subject who refused to have his book illustrated from hearsay and took care that it be done directly from the original objects represented." (Ivins 36)
- The next year, in 1486, at Mainz, there appeared the first edition of Breydenbach's *Travels*. This was the first illustrated book of travel to come from the press.
- In 1491, in Florence, the first book on commercial arithmetic appeared, containing dozens of simple but elegant tiny woodcuts. Also in 1491, *Hortus Sanitatis* was published in Germany; the highly esteemed medical text incorporated the 5th century Apuleius Barbarus’ *Herborium* whose text and drawings had circulated for 1000 years.
- Gregorius' series of editions of the *Fasciculo de Medicina* of Johannes Ketham, the first of which was printed in 1491, displays illustrations of various dreadful-looking surgical instruments and in 1493 large pictures were added, each occupying the whole of folio page, and representing a dissection, a consultation of physicians, and the bedside of a man struck down with the plague.
- In 1493, the most important of the chronicles in respect to wood-engraving, the *Chronicle of Nuremberg*, was published in that city in 1493. It contains close to 2000 cuts and its distinction rests in the fact that, for the first time, were printed woodcuts simply in black and white, "which were looked on as complete without the aid of the colorist, and were in all essential points entirely similar to modern works." (Woodberry)
- In 1498, arguably the greatest illustrated book of the fifteenth century appeared — Albrecht Durer’s *Apocalypse*, celebrated because of the mastery with which the woodcuts were designed and executed by Durer himself.

As a practicing archaeologist, I am very aware that by the nature of our discipline, we seemingly destroy the record we are trying to recover and interpret. We take the three-dimensional physical record of the hidden site (within which is the fourth or temporal dimension) and turn it into a two-dimensional linear record. My own work with AutoCAD attempted to rebuild the site with all the recovered material and the architectural features and to provide, in essence, a three-dimensional world.

For example, Peter Boyce describes the network of electronic information available to astronomers including well-designed electronic journals which support video, large data tables and electronic
enhancements as well as the [Astrophysics Database System (ADS)](http://adsabs.harvard.edu), a linked searchable abstract database of older information (406).

7. Professor Rzepa suggested (in his email of February 19, 2001) that I review a specific molecule using Chime. It can be found at [http://www.ch.ic.ac.uk/local/organic/halo.pdb](http://www.ch.ic.ac.uk/local/organic/halo.pdb). About this molecule, he wrote:

> A year or two ago now, a pharmaceutical company was bringing an anti-malarial drug to market. As is usual they had made 100s of possible candidates, and then had to prove that they were safe. One of the many procedures involved separating the two components of a drug known as "mirror images", a phenomenon which is a feature of the 3rd dimension (a failure to recognise its importance had in part caused the thalidomide problems). Some of the candidates could be separated but many could not, and they did not understand why. When we got involved, our first efforts centred around looking at the drug in 3 dimensions wearing "3D" headsets, and quite suddenly one day we noticed a remarkable and most unexpected feature of the drug that we now know causes the phenomena the drug company had experienced. . . . If you wish to explore the "key" feature, look for the red atom (display => spacefill => van der Waals from the right mouse menu) and note that it overlaps with a white (hydrogen) atom adjacent. This overlap chemists call a hydrogen bond, and it's both quite unexpected, and responsible for the peculiar properties.

8. The [Molecule of the Month Web site](http://www.dlib.org/dlib/february01/02featured-collection.html) is based at the University of Bristol in the United Kingdom. In addition to containing many interesting chemical facts, the site provides a good example of the way the Web can be used to create a truly worldwide database of information. Each month, this page features a few paragraphs of information about a particular molecule, written in a way that is both interesting and informative. The content is easily understandable to people who possess only a basic knowledge of chemistry (e.g., science undergraduates). The pages might originate from industrial labs, university chemistry departments, schools, or even science journalists, and can be accessed anywhere in the world that's connected to the Web. Over the past five years, the list of featured molecules has grown into a useful archive of chemical data, and it has highlighted recent advances in chemistry as well as the technology of the web." *D-Lib*, February 2001.

9. A very recent article explores the possibilities of integrating both text descriptions and image contents into an effective search engine. See Guojun Lu et al.

10. Michael Grossberg notes that "electronic publishing — with its propensity for hypertext links and multiple layers of argument and evidence — seems hostile to the linear argumentation and explicit interpretive narratives that most historians favor." (B7)

11. See Steven E. Arnold's article in *Searcher* (January 2000), which forecasts that "Displays — whether on a flat panel or some snazzy new display drive — will feature multiple windows in which different, unrelated ‘information events’ transpire. This is less like having Word and Excel open on a single desktop and more like looking at a display space with a commercial television program or two running, a local application, a network application buzzing away and a couple of real-time video-conferences going. Sound confusing? It won't be to the younger users." (Arnold: 94)

12. See Mirapaul, who writes "[Three-Dimensional] Space. It may not be the Internet's final frontier, but it could be its next one" and quotes "Neil Trevett, president of Web 3D Consortium, an industry group trying to establish the technical standards for delivering 3-D data online. 'The question is when, not if.'" (Mirapaul: 4)

13. From Peter Hirtle's editorial in the March 2001 *D-Lib Magazine*: Some of the most exciting experiments in digital libraries seek to develop new tools and services for scholarly communication that can transcend what is possible in the print environment. The article by Herbert Van de Sompel and Oren Beit-Arie in this month's issue of *D-Lib Magazine*, which describes the rich possibilities present when OpenURLs are combined with the SFX framework, is a good example of the type of innovative new service only possible in a digital environment. Other research is under way to determine how to duplicate in a digital environment the best features of past methods of scholarly communication (certification of findings by the scholarly community; wide-spread dissemination of results to relevant audiences; and the free use of materials in the library, for example.

14. See [James L. Weinheimer's letter to the editor](http://www.dlib.org/dlib/february01/02featured-collection.html) in the March 2001 *D-Lib Magazine* which describes
succinctly the importance of description in the catalog but argues that for "electronic resources and their ever-changing states, this level of description will only be valid in those rare cases when the site hasn't changed from the time of the metadata creation to the moment someone uses the metadata record. ... As a result, I feel that the purpose and task of bibliographic description as we have always known it is destined for a complete overhaul, but no one is even considering this as far as I know. . . . For now, discovery is the best and most fruitful area for the task at hand."  

15. Bill Arms writes that "research libraries, as organizations, have great difficulty in developing the technical skills and implementing the revolutionary changes that are needed for automated digital libraries."  

16. See, for example, the references collected on the Berkeley site. See as well the Web debates sponsored by Nature on the topic of the impact of the Web on publishing the results of original research. And finally, see the online book, and especially the indicated chapters, The Transition from Paper: Where Are We Going and How Will We Get There? Edited by R. Stephen Berry and Anne Simon Moffat. (Published online, 2001)

- Chap. 4: "Scientific Journals of the Future," by Steven M. Bachrach
- Chap. 7: "Electronic Clones vs. the Global Research Archive," by Paul Ginsparg

17. The Association of Learned and Professional Society Publishers, 18th International Learned Journals Seminar, April 12, 2002.  

18. Much of the work that will change scholarly communication and, as a result, the activities of the research library — e.g., open reference linking in the web-based scholarly environment as cited in note 12 — is happening outside the research library. See Weinheimer in note 14 for a critical library activity which he believes is required.

Reference List

Agricola, Georgius. De Re Metallica. Basel, 1556


http://www.theatlantic.com/unbound/flashbk/computer/bush.htm Also available in JEP Vol. 1, No. 1


Links from this article:

Association of Learned and Professional Society Publishers (ALPSP), http://www.alpsp.org

ALPSP 18th International Learned Journals Seminar, "We can't go on like this: the future of journals," http://web.archive.org/web/20030605124814/http://www.alpsp.org/s120402.htm

Astrophysics Database System, http://adswww.harvard.edu

"As We May Think" by Vannevar Bush, [doi: 10.3998/3336451.0001.101]

AutoCAD, http://usa.autodesk.com/

Chime software, http://www.mdlchime.com/chime

D-Lib, http://www.dlib.org

D-Lib Featured Collection: Molecule of the Month (February 2001), http://www.dlib.org/dlib/february01/02featured-collection.html

First Monday, http://www.firstmonday.org


JEP, http://www.journalofelectronicpublishing.org/

"JIME: An Interactive Journal for Interactive Media" by Simon Buckingham Shum and Tamara Sumner, http://www.firstmonday.org/issues/issue6_2/buckingham_shum

Journal of Interactive Media in Education (JIME), http://www-jime.open.ac.uk

Journal of Molecular Modeling, http://www.chemie.uni-erlangen.de/ccc/jmolmod/