47. [Introduction] Seeing and Writing

Although writing is visual, the appreciation of the visual aspects of it competes with understanding what is written, as J. David Bolter pointed out in the following selection. This competition can be healthy or destructive; Bolter's point is not merely to state what typographers have known for centuries. Rather, he describes how the history of typography and printing relates to the present movement of writing onto the computer screen. Marshall McLuhan similarly considered how the print revolution can inform an understanding of contemporary changes in electronic media—particularly in *The Gutenberg Galaxy* (the last chapter of which appears in ◊13)—but Bolter's essay further explores how changes in new media influence our concepts of reading and writing. Bolter has gone on to explore how this, in turn, influences established media, in a process he and Richard Grusin have called "remediation."

Good it

Certain elements of computer text are very closely based on print forebears, while others have no basis in earlier technologies of writing; Bolter notes, for instance, the ability to resize windows and have the text re-flow instantly to fill the new rectangle. An understanding of new media can only come when truly novel elements can be divided from those which are imitative, using scrutiny of the sort Bolter applies. The electronic spreadsheet is certainly native to the computer, but as Bolter (along with Ben Shneiderman ◊33) has pointed out, it relates to structures that are evident in paper accounting practices as well as elements of the printed book, such as diagrams. Numbers and letters are not meeting for the first time in electronic writing space; neither are text and image. The way these elements come together on the computer is influenced by movie titles as well as the practices of medieval monks, and there are lessons about the integration of these elements that are to be found in many contexts in the past.

In the current media ecology, the network of influences between different media, new and old, is dense. (This is not an entirely novel situation; media have influenced each other for as long as they have existed, and as new media have been introduced the relationship has seldom been as simple as the replacement of the vanquished medium by the victor.) While a scholar can hardly hope to be an expert on every form of communication—on every "extension of man," as McLuhan would have it—thorough understanding of a particular medium being used for a particular purpose can often be accomplished by understanding that medium's close relatives, and by close study of several relevant works in those media. Bolter's consideration of the history of typography, to inform his understanding of writing on the computer, is clearly of benefit to those with a special interest in the medium of text (alone or in combination with other media) and the concept of reading; it is also an excellent example of how, in general, one might approach new media from adjoining, better-understood territory.

—NM

right

Are electronic spreadsheets hypertext? Although Bolter asserts that they are, and Ted Nelson's vision would certainly seem to accommodate them, not all critics of hypertext would agree. This points out an advantage, for critical discussion, of rigorously defined categories such as Espen Aarseth's "cybertext" (◊52). Of course, categories such as hypertext and cybertext must still draw boundaries that provide for interesting critical discussion; precision alone is not enough. Thus the more essential question: are spreadsheets interesting to consider alongside certain other types of computer activity?

013 193

033 485

Helvetica

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Seeing and Writing

J. David Bolter

A generation ago, the classical scholar Eric Havelock could still claim that "[the] visual development of the written signs has nothing to do with the purpose of language, namely instantaneous communication between members of a human group" (Havelock, 1982, p. 53). This attitude was appropriate to the age of print because printing reduced each letter in a text to a visual minimum. Unlike the calligrapher, the typographer's art was to make the letter unobtrusive, to convey the various letter shapes without distracting the reader. And typographers have been so effective that we as readers hardly notice the subtle differences that exist among the various typefaces used in books today. As children we are trained to read silently and quickly, looking through the printed page rather than at it. *

As we now move beyond the technology of printing, it is no longer appropriate to dismiss the visual history of writing—the changes in both the written signs themselves and their deployment on the page or screen. No writing system is static. Even the letters of our alphabet have continued to develop since Roman times. In the Middle Ages there was an elaborate and ever-changing population of scripts throughout Western Europe. The age of print has been unusually conservative in character, but even it has not been immune to change. And the computer now promises to accelerate the development again, as it offers writers the opportunity both to create their own character fonts and to deploy pictorial elements in new ways.

The layout of the text (the surface of the roll, the page of the book) has always developed along with the individual elements. When the writing space became conceptually narrower in the shift from picture writing to phonetic writing, the layout became narrow and cramped as well. Early Greek writing was linear in concept and appearance, while all the subsequent development in papyrus and parchment manuscripts and in printed books has served to reestablish the second dimension in the visual structure of the text. In later antiquity, writers regained their interest in the diagram or illustration placed beside or incorporated into the space of the text. Since that time our writing space has been a hybrid of verbal and pictorial elements. Even the conservative technology of print has permitted pictures and more recently mathematical graphs and diagrams to flourish. The computer now adds the capability of animation and so combines pictorial, alphabetic, and mathematical writing into one dynamic whole.

Mechanical Letters

Early printed books attempted to replicate manuscripts both in letter form and in layout. In cutting his type, Gutenberg copied the Gothic script of his day, including all the ligatures and abbreviations, altogether about 300 different elements. (See Steinberg, 1959, p. 31.) It took several decades for printers to realize that there was no need to use abbreviations and ligatures that rendered the text easier to write (by hand) but harder to read. Each letter of the same type could now be identical, guaranteed by the method of production (casting lead in copper matrices). The precision of the machine now replaced the organic beauty of the handwritten page.

Mechanization did not eliminate human craftsmanship from the process of writing. Instead, it deferred the craftsman from the final product of ink on paper. Letters were still handmade: a craftsman fashioned a set of steel punches that embodied the design for a typeface. These punches were pressed into matrices to serve as molds for the lead type itself. Some early punchcutters actually cut more than one form of the same letter in order to imitate the variation of the scribe, but this practice was clearly misplaced in a technology whose purpose is identical reproduction. Letter forms evolved much more slowly in the age of print than in the previous age of manuscripts. The gradual trend was to pare down the visual form of the letters—in effect to define the writing space with progressively less ink and more white space. Serifs became straighter and thinner, and there was greater contrast between thick and thin strokes. The whole typeface betrayed less and less the hand of the craftsman. The trend reached an extreme in the late 18th century with the designs of Didot and Bodoni.

In the 19th century, mechanization intensified with the development of steam-driven printing presses and the Linotype. Yet in the design and use of typefaces and in the appearance of the printed page, the result was not greater standardization, but greater variety, a sense of growing freedom in what could be shown. The pantographic punch-cutter made it possible to cut a new letter in steel simply by tracing an enlarged pattern of the letter (Lieberman, 1978, pp. 54–55). If in the 16th and 17th centuries, most printers were satisfied with some form of Garamond, printers in the late 19th and 20th centuries could choose from hundreds or thousands of faces. They experimented with forms that earlier printers would have considered barbaric or unrecognizable (but that medieval illuminators might have appreciated). Other typographers reacted to this excess by creating faces such as Helvetica and Futura that were free of all unnecessary strokes.

Nevetheless, the printed page has remained a conservative writing space. The thousands of exotic, so-called "display" fonts appear in advertising, but seldom in books. For book production, the typographer may now choose from dozens of book fonts (with names that signify both tradition and innovation, such as Times Roman, Modern, Baskerville, and Garamond No. 3) which his or her trained eye can distinguish for readability, "color," and "tone." But such distinctions are so subtle that the average reader cannot identify any of the common book fonts. On the other hand, if any **OF** the **thousands** of **display FONTS** were used in printing books, the reader could tell immediately that something was wrong. Printing is a frozen medium in more ways than one: its letter forms stabilized between the 16th and 18th centuries and have since changed only a little. And depending upon its use as an auxiliary to printing or as an alternative writing space, the computer can either reinforce this stability or sweep away the whole tradition of typography.

Electronic Letters

> The art of letter design will not be fully understood until it can be explained to a computer . . .
>
> —Donald E. Knuth, 1982, pp. 5–6

If the trend in the age of print has been to make the visual symbol simple, unornamented, and mathematically precise, a backlash developed in the 19th century led by William Morris, who distrusted mechanization in almost any form. In England as elsewhere, 19th-century printers had been aiming for quantity rather than quality. The demand for inexpensive newspapers and books was exploding, and inventors were trying to clear the bottlenecks in production by developing mechanical printing presses, new forms of cheap paper, and mechanical typesetting. But when Morris founded the Kelmscott press in 1891, he was not interested in mass production. Instead of industrialized simplicity, he aimed for ornament and organic form, a return to the first century of printing or to age of the manuscript. He modeled his Golden Type on the work of the 15th-century printer, Nicolas Jenson. For his edition of Chaucer, he went further and designed a Neogothic typeface. He chose a hand press and handmade paper. The resulting books were beautiful, but themselves excessive, their pages dense with ink and full of ornamentation—and utterly different in spirit from the early printing that Morris meant to imitate. (See Steinberg, 1959, pp. 29–30.) The irony is that these nostalgic books could only have been produced in the Industrial Age: the precision of his Chaucer was greater than was possible in a Renaissance printed book or a medieval manuscript. It was the advance of technology that permitted Morris to go back in this characteristically Victorian way: Morris took photographic enlargements of printed pages in order to study old typefaces. (See Morris, 1982, p. xxxiv.) Morris' work in printing was a kind of technological nostalgia that celebrated the modern technology it appeared to reject.

A similar nostalgia has been evident in the first decade of word processing. The word processor is an attempt to harness the computer in the service of the older technology of print, and the word processor's presentation of text is nostalgic, in that it looks back to the aesthetic criteria of the printing press. The electronic medium in fact allows complete graphic freedom: the writer may ultimately control each pixel on the screen in representing letters, diagrams, or images. When writers are first given this freedom, on personal computers like the Macintosh, they indulge in greater excesses than Morris, decorating their texts with a variety of type sizes, styles, and fonts. They mix elements from the whole history of typography, often without any sense of propriety or proportion. Professional graphic artists can lodge a similar complaint: bit-mapped personal computers permit untrained users to indulge in a riot of graphic design. Often it is graphic design appropriate to the printed brochure or the billboard rather than the computer screen.

There is an inevitable degeneration in the quality of typography and graphics in the new electronic writing space, because the computer encourages the democratic feeling among its users that they can serve as their own designers. Anyone can experiment with type size or style when the computer provides the fonts and drops them into place at the writer's request. Anyone can create and insert his or her own illustrations with the help of automated drawing programs. The new technology thus merges the role of writer and typographer that had been separate from the outset of the age of print. In the age of print, typographers had access to special tools and the skill to use them, and they made the decisions about page layout. Printers have always understood their role as craftsmen, and their guilds, which served to protect their aesthetic as well as the economic prerogatives, remained strong until the middle of the 20th century. Now the electronic writer and designer can own and use professional tools without bothering to develop professional skills.

However, electronic writers are dabbling in the wrong art, if they worry too much about the typography of their text. The pixels of the electronic medium define a space inherently different from that of ink on paper. At present the electronic space is coarser: it is not possible to create subtly curved or bracketed serifs in letter forms or finely organic lines in drawing. The computer screen will continue to improve in this respect: pixels will grow smaller and create a denser space. But the discrete character of computer graphics will not change in the foreseeable future and must always remain in tension with the continuous character of ink on paper, parchment, or papyrus. The impermanence of the electronic image also discourages an attention to fine visual detail. Electronic writers sense that their writing and therefore their typography is always subject to recall and change. The traditional typographer has exactly the opposite impression—every letter must be in its place, because there is no way to recall 1,500 printed copies if an error is discovered. In this sense, even the humble word processor operates in a visual space different from that of the printing press and the typewriter. Typographers and graphic designers who complain about the mess that naive users make on their terminal screens are themselves children of a different technology and are apt to judge the computer's writing and drawing space in the wrong terms.

Professional typographers also use the computer. Just as the word processor has replaced the typewriter, so computer editing and photocomposition now dominate professional book production. Most books today are published by electronic photocomposition; metal type has almost disappeared, even for fine book production. The computer introduces a new degree of mathematical rigor in the design of letter forms themselves. One way to produce electronic fonts is to trace and digitize enlarged photographs of the letters. The other, more intriguing method of computer design is not to copy old letter forms point by point, but rather to generate new letters mathematically. The computer scientist Donald Knuth has used parameterized equations to define the curves of the letters. The computer generates the points by working out the equations. What Knuth has done is to throw the alphabet into the space of analytic geometry. The idea of geometrically defined letters is an old one: it dates back to Renaissance typographers, calligraphers, and artists, including Pacioli, Albrecht Dürer, and Tory (Lieberman, 1978, p. 41). But rather than using compass and straightedge, the computer specialist creates letter forms by numerical analysis, precisely the task for which the electronic computer was originally developed. Computer typography reduces the writing space to a Cartesian plane, in which every letter is determined by a set of numbered lines or points. It is the triumph of the mathematization of writing that never quite succeeded in the era of mechanical printing.

On the other hand, the use of the computer to mathematize printing is also an example of technological nostalgia. It turns our attention back to the medium of print, applying mathematical precision in order to perfect the appearance of text on the page. Perfection is still defined in terms established by printers in the 15th and 16th centuries—as the clean, crisp, static image that occupies the monumental writing space of ink on paper. Work on computer typography directs our energies away from appreciating the electronic space in its own right—a space in which the subtleties of type size and style may no longer be important to the writer's or the reader's vision of the text.

The Electronic Page

Typography in print begins with the letter and never goes much further. A glance at the typographer's handbooks shows how much importance is placed on the choice of the typeface itself. Indeed, once the typefaces and styles (and perhaps colors of ink) have been chosen for a book, there are very few decisions left to be made. Each page will be a rectangle of text with some white space around it. Illustrations will occupy blocks reserved for them within the rectangle or on separate pages altogether, and in any case illustrations are relatively rare in "serious," discursive books. Advertising and magazines present many more possibilities for creative design, but the layout of a book is as conservative as the choice of fonts appropriate to the book. And many typographers would agree that the decisions of layout all flow from the letter. The printing press is really a letter processor.

In some ways the earlier handwritten page offered more freedom of design than the printed page. Already in the Carolingian period, scribes used a different script (uncial) to indicate titles and demarcate sections. The word "rubric" comes from rubrication, the medieval technique of beginning a text with a large red capital, often elaborately decorated. By the 13th century scribes had developed a number of visual cues to help the reader locate text and keep his or her orientation. Different styles and sizes of letters, different colors of ink, section numbers—all these devices were pioneered in the Middle Ages and then standardized in the age of print. Probably the most important visual structure in the medieval codex was the marginal note. Medieval texts were often arranged into two or more layers on the page. The center of the page contained the more ancient and venerable text, while the margins offered explanation and commentary added by one or more scholars. This structure helped to orient the reader. It was relatively easy to move back and forth between text and notes, certainly much easier than it was for the reader in the ancient world to juggle several rolls of papyrus. Marginal notes told readers what to look for and provided constant support in the task. Many Renaissance or later readers found these notes to be a hindrance, the weight of centuries of misreading of the text, and printers began to clear the page of this interpretive material, allowing the text to occupy the whole of the writing space and therefore to speak for itself. Notes moved to the foot of the page and eventually to the back of the book. But in banishing the notes modern printers have sacrificed both the immediacy of reference and the sense of visual and intellectual context that marginal notes provided to their medieval readers. (It is only in electronic text that we can recapture both immediacy and context.)

In the modern printed book, the space is simple and clean. Different texts do not compete in adjacent spaces for the reader's attention, as they still do in a magazine or newspaper. In a magazine the text is divided into blocks of varying shapes and sizes, and readers find themselves pulled back and forth among the blocks. The page layout reflects the topical nature of the material—a combination of advertisements, notices, and long and short articles. A magazine or newspaper is in this respect closer in spirit to the topographic writing space of the computer, where the "typography" also mirrors the topical nature of the text itself. Larger units of text together with images can be isolated on the computer screen. The screen becomes a magazine page in which units even rearrange themselves to meet various needs.

In the current generation of machines, for example, the so-called "window" is the defining feature of computer typography. A computer window is a framing device: it marks out a space for a particular unit of verbal text, graphics, or both, and it frames the writer/reader's view of that space, which is an indefinite two-dimensional plane. The window may show only a portion of the plane at a time, but often the view in the window can be adjusted or scrolled to reveal other parts. In some computer systems windows can be "tiled"—set side by side so that the writer/reader can look onto two or more planes at once. In other systems the windows can be "stacked," so that the planes of text and graphics pile on top of each other, again without really touching. The whole electronic writing space becomes a stack of two-dimensional writing surfaces. Of course, a printed book is also a stack of two-dimensional planes or pages, but the great difference is that printed pages stay in one order and, except in novelty books for children, each page completely obscures all the pages underneath it. Working at the computer, the writer/reader can move one window aside in order to view parts of the windows below; he or she can reorder the stack by plucking one window from below and placing it on top. If the windows contain different texts, say two chapters in a book, the reader can move back and forth adding to and cutting from each. This new typographical space is sometimes said to have two and a half dimensions, because the writer looks straight down on the stack of planes. The writer cannot move around or behind the planes in a full third dimension, although this may well be possible in the next generation of computer software. (See Levy, Brotsky, & Olson, 1988, especially pp. 3ff.)

No previous writing technology has offered anything quite like the windowed typography of the current microcomputer.

Switching between windows is in some ways like shuffling papers in a notebook, but nothing in previous technology corresponds to enlarging the size of the window (the text immediately rearranges itself to fill the gap) or scrolling through text in a window. These operations show that the text is not pasted to the window, as it is to the printed page. In fact, both the window and the text may change at any time. The window may fly like a helicopter over the textual plane, or the text may realign itself to suit the dimensions of the window. Visible windows or portions of windows compete for the reader's attention and actively change shape and status when they succeed in attracting attention. (See Fig. 47.1.)

If we are viewing a hypertext, the windows take on a structural significance. In a hypertext there are operational links between units: text in one window can be linked to text in another. Following a link can make windows appear, disappear, or rearrange themselves so that the destination text comes to the front of the screen and captures the reader's attention. This animation becomes an element of electronic typography. It is as if in a printed book the pages reordered themselves to put the next interesting paragraph before the reader's eyes.

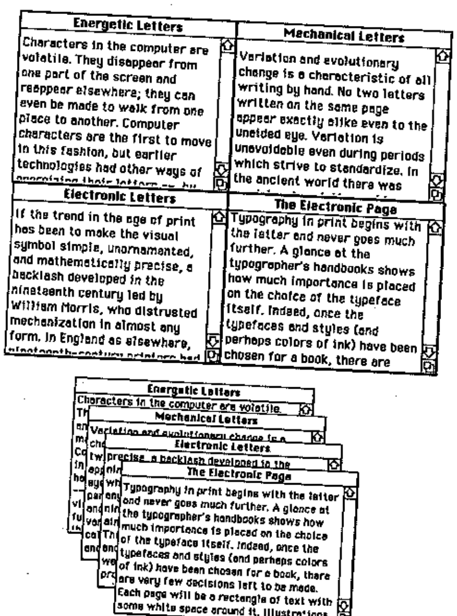

Figure 47.1. (a) Tiled windows simply divide the screen into two, four, or more rectangles; all are in the same plane. (b) Stacked windows occupy different planes or levels closer to or further from the reader.

Even within a single window, objects (images and verbal text) can be stacked: text can slide underneath a graphic, or the graphic itself may be moved to reveal another graphic. The layout of the screen may always change, and the reader may participate in those changes. Like the text itself, the typography is not determined prior to the reading, but is instead a manifestation of the act of reading: it is one aspect of interactive text. The screen enters into a series of configurations, and that evolving series is the visual expression of a particular reader's journey through a textual structure. No one configuration is likely to be as attractive as a page that a professional typographer can produce for print. But no one configuration lasts very long, and it is the movement from one configuration to the next that carries much of the meaning of an electronic text. In a conventional printed text or manuscript, the reader's eye moves along the letters, and possibly back and forth among images, whereas the letters and images themselves are static. In electronic text both the reader's eye and the writing surface are in motion.

Computer animation can take a variety of forms. It is not only a matter of programmed motion pictures, still images shown one after another to give the illusion of a continuous scene. Computer text and graphics can be animate in the sense of having their own organic impulse, of appearing to move or change according to their own logic and in their own time. Even alphabetic texts can appear at various locations on the screen and change or disappear at intervals. (See Nishimura & Keiichi, 1985.) Such animation requires a peculiar reading technique in which the text moves under the eye rather than the reverse. Yet this kind of reading is already common in electric and now electronic billboards that deliver news and advertising. Audiences have been reading unstable text for decades in the form of the subtitles in motion pictures. The difference is that the computer allows any writer to play with the movement of text and gives the writer a freer space for such experimentation.

Reading the complex electronic page demands an attention to text, image, and their relationships. Readers must move back and forth from the linear presentation of verbal text to the two-dimensional field of electronic picture writing. They can read the alphabetic signs in the conventional way, but they must also parse diagrams, illustrations, windows, and icons. Electronic readers therefore shuttle between two modes of reading, or rather they learn to read in a way that combines verbal and picture reading. Their reading includes activating signs by typing and moving the cursor and then making symbolic sense of the motions that their movements produce.

Pictures in the Text

Moving pictures into the computer's writing space is remarkably easy. But the electronic space demands a translation: the image must be digitized, all continuous lines and shadings must be transformed into a binary coding. It is possible to feed a picture taken by a video camera into the computer—to capture a portion of the continuous spectrum of the visible light, transform that portion into a series of bits, and save those bits as a picture in the machine's memory. A graphics program can then isolate a portion of the picture, shrink or enlarge it, produce a mirror image or a negative copy. But the program can work all these further transformations only because the picture has been encoded. And in general, the computer can combine words and pictures so easily because both are represented in the same binary code. The digitization of images inevitably strips away their context and allows the machine, or rather its programmer, to define new contexts. The further step is to turn some pattern of bits into an operational symbol or icon. An icon, we recall, is an image that stands for a document or a program in exactly the same way that one pixel pattern stands for the letter "A," another for "B," and so on.

In electronic writing, then, pictures and verbal text belong to the same space, and pictures may cross over and become textual symbols. The unified character of the electronic space is unusual, though not unprecedented in the history of writing. The development of phonetic writing, while it did not eliminate pictures altogether from the writing space, did create a dichotomy between image and phonetic sign. Phonetic writing pulls the writer and reader toward the pure linear space of spoken language, whereas pictures, diagrams, and graphs pull them back toward a pictorial space, which is at least two-dimensional and whose meaning is not strictly codified. Different writing technologies have responded to this tension in different ways.

In Egyptian writing, for example, there was an intimate relationship between pictures and text, both in wall-painting and on papyrus. Hieroglyphs were themselves little pictures, and so both visually and conceptually Egyptian writing could blend smoothly with illustration. (See Weitzmann, 1970, pp. 57–69.) The Greek and Roman writing space was not as friendly to pictures. The ancients regarded writing as an instrument for holding spoken words in a fixed form until they could be revived by the voice of the reader. Book decoration was, therefore, an insignificant art in antiquity. (See Nordenfalk, 1951, pp. 9–20.) From the pure alphabetic space of early Greek inscriptions, it took several hundred years for the Greeks to readjust and admit pictures and diagrams fully into the writing space. (See Weitzmann, 1970, pp. 97ff.) The growing importance of pictures in late antique books formed a link with the Middle Ages. Medieval manuscripts presented a complex space of words, pictures, illustration, and ornamentation—the most complex prior to the electronic medium. In medieval books, pictures were often separated from the text and given prominence as full-page miniatures. But there was also a new impulse to decorate the writing space—to create the illuminated letters that were unique to the medieval writing.

Like computer icons, medieval illuminated letters functioned simultaneously as text and picture. In fact, medieval illumination threatened to turn letters back into images or abstract designs and sometimes made the letters all but impossible to read. (See Alexander, *The Decorated Letter,* 1978, p. 8.) Perhaps the best-known example is to be found in the *Book of Kells*, where the Greek letters chi-rho-iota (standing for "Christ" in Matthew 1.18) occupy a whole page. The design is so intricate that the shapes of the letters are almost completely obscured. Yet these illuminated letters remain part of the verbal text: they have to be included in order to read the verse. They constitute the perfect interpenetration of picture and word space. The *Book of Kells* is abstract illumination, but medieval illuminators could also transform an individual letter into a miniature picture with recognizable human or animal subjects. Sometimes the letter was distorted to contain its subject; sometimes the humans or animals were elongated or distorted to fit into or around the letter. The initial letter was often out of proportion to the rest of the text and could encompass almost anything in its luxuriant growth—fantastic creatures as well as elements of the natural world. It is as if the illuminator were trying to absorb the whole visual world into the letter, which itself had grown enormously large in order to receive the world. Medieval illumination embodied a dialectic between writing and the world; it was a means by which writing could describe or circumscribe the world—not symbolically through language, but visually through the shape of the letter itself.

The technology of print favored a stricter separation of the verbal and pictorial writing spaces. Diagrams and illustrations were as popular as ever. But for technical reasons, these images were not as well integrated with the words, as they had been in the best medieval traditions. (See Tufte, 1983, pp. 181–182.) Woodcut illustrations were segregated from the printed text as a product—the wood betrayed much more the hand of the craftsman. Many printed books have contained no illustrations at all, just as many medieval manuscripts contained none. The ideal of the printed book was and is a sequence of pages containing ordered lines of alphabetic text. When the woodcut was replaced by the copper engraving, more elaborate and finely drawn images became part of the printed book. Printers and authors became more ingenious in putting words and images together. The 17th and 18th centuries were the age for allegorical frontispieces and illustrations. (Perhaps the most famous example is the crowded frontispiece in Vico's *New Science,* which Vico patiently explains in his introduction embodies point for point the substance of his interpretation of history. See Vico, 1948, pp. 2–23.) Today it is technically possible to place pictures and illustrations in and around text, and even to superimpose images upon the text.

Photolithography allows any image to be taken onto the page. Some books (especially those designed for young children or for coffee tables) are mostly pictures. Yet the pictorial and verbal spaces are still not as subtly combined as they were in medieval illuminated manuscripts. Most books for adult readers still segregate blocks of text from blocks of pictures, and pictures or plates are often gathered together in the middle of the book to lower production costs. On the other hand magazines, newspapers, advertising tabloids, and billboards all tend to subvert the primacy of linear verbal text in our culture. They work against the ideal established by the printed book.

So, from the nadir of early Greek writing, in which there was no room for pictures, the writing space of the papyrus roll, the codex, and the printed book have permitted a variety of relationships between picture and text: pictures have been decorative, explanatory, allegorical. They have commented on the text; the text has commented on them. But only in the medieval codex were words and pictures as unified as they are on the computer screen. On the screen, as on medieval parchment, verbal text and image interpenetrate to such a degree that the writer and reader can no longer say where the pictorial space ends and the verbal space begins.

Diagrammatic Space

The diagram is a kind of picture writing that can only exist after the invention of phonetic writing. It is a codified picture, in which each element has a well-defined reference: it is verbal writing with picture elements. Allegorical pictures are diagrams, whose elements are images that recall the world. They now seem quaint precisely because we expect diagrams to consist of abstract rather than iconographic elements. There is in fact a surprisingly long tradition of abstract diagrams as aids to exposition. Plato used a line diagram to explain his epistemology in the *Republic.* The tree diagram, so important for computer structures, is very old: there survive early medieval manuscripts that display hierarchical information as a tree. (For example, there are trees in the manuscripts of Cassiodorus; see Mynors, 1937, pp. xxiii–xxiv.) Because of the tradition of illumination in which writing and drawing coexist in the same writing space, medieval writing was receptive to both allegorical and abstract diagrams. Among the most famous and elaborate diagrams were those of the 13th-century theologian, Ramon Llull. (See, for example, Llull, 1985, pp. 105–109 and plates 12–13.) Diagrammatic representations of thought continued in print, and diagrams, like illustrations in general, flourished after the shift from woodcuts to copper engravings. Giordano Bruno and other Renaissance magi, influenced by Llull, produced books of the greatest visual interest, filled with abstract and allegorical representations of thought. (For a discussion of Giordano Bruno's work and influence, see Yates, 1964.) More sober writers also used diagrams. Tree diagrams were particularly popular for displaying a ramified subject matter.

All diagrams in manuscripts or in print are of course static representations. The writer and the reader have to activate these diagrams mentally, just as they activate the verbal text. For the first time in the history of writing, electronic technology now offers its writers and readers fluid text and truly animated diagrams. The animation is no mere gimmick. It reveals again the hypertextual character of electronic writing in which distant elements can be linked together and these links can be conceptually active.

The popular computer spreadsheet is an example of an active diagram and indeed of a hypertext. The spreadsheet enables the user to display and modify relationships among numerical entries, usually budgets or accounts of some kind. The user sees a grid of cells on the screen and fills the rows and columns of cells with appropriate numbers, just as an accountant would do with pencil and paper. For example, if the spreadsheet represents the income of a small business, its columns might be months of the year, and its rows might be sales, taxes on sales, and so on. (See Fig. 47.2.) The electronic spreadsheet is far more flexible than a sheet of paper, making it easy to copy, modify, and rearrange the values. An electronic spreadsheet is also a text, not simply because there may be verbal labels for the columns and rows, but because its cells hold the values of interrelated variables. The spatial relationships of the cells define relationships among the variables. The diagram, like a verbal text, is a

a

	May	June	July	Quarter
Sales	$1000	$800	$1000	$2800
Taxes	$50	$40	$50	$140
Total	$1050	$840	$1050	$2940

b

	May	June	July	Quarter
Sales	$1200	$800	$1000	$3000
Taxes	$60	$40	$50	$150
Total	$1260	$840	$1050	$3150

Figure 47.2. In this spreadsheet, the first three columns each record one month's activity. The fourth column (Quarter) is automatically keyed to be the sum of the first three. The first row represents sales, the second row (Taxes) is automatically set to be 5% of the first row, and the third row (Total) is the automatic sum of Sales and Taxes. Now if the user changes the figure for Sales in May from $1000 to $1200, the change automatically propagates to recompute the other underlined cells. Spreadsheet a becomes spreadsheet b. The cells in this spreadsheet are thus linked together to form a numerical hypertext.

symbolic structure and is open to symbolic manipulation. Thus, a column or row of figures can be added automatically; an entire row can be reduced by a factor of three; two columns can be switched. Individual cells can also be linked together. If the value of cell C is defined as the sum of the values of A and B, then each time the user changes A or B, C will change automatically. An accountant can link together dozens of cells with intricate calculations; as he or she alters figures, the changes propagate automatically throughout the grid. The speadsheet becomes a dynamic tool for seeing the effect that one change in a budget will have on other items. Its power is due to the fact that it is hypertextual: each of the cells is a unit, and the cells are interconnected in a network of dependencies. Before the computer, a diagram that was interconnected and active in this sense existed only in the imaginations of Llullists and Hermetists of the Renaissance.

Numbering Space

A spreadsheet in fact lies halfway between a verbal text and a true mathematical diagram or graph. For in a graph the writing space itself is numbered. The graph has long been an important form of picture writing and has gained steadily in status since the 18th century, as it has been applied to data from experimental science. (See Beniger & Robyn, 1978, pp. 1–11.) It comes as no surprise that the computer is the ideal space for drawing and analyzing graphs.

Diagrams were important even in ancient geometry: the *Elements* of Euclid contained proof after proof describing how to construct geometrical objects with straightedge and compass. But the writing space of Euclidean geometry was a synthetic space in which numbers themselves were conceived in geometrical terms. The situation changed with the development of Cartesian geometry in the 17th and 18th centuries. The Cartesian writing space is numbered. The points of a line can be set into correspondence with real numbers, and two perpendicular, intersecting lines can mark out a grid so that every point in their plane has a unique numerical identity. These lines or axes indicate the scale by which the writing itself (the data points) is measured. The modern graph, therefore, belongs to a space different from the verbal space of a printed or handwritten book. In the verbal space the rows of letters mark out a horizontal scale, but only a very coarse one. If one letter is a bit higher or lower than the others in the same line, only the attractiveness of the line is affected; the meaning of the sentence does not change. But in a Cartesian graph, a raised or lowered data point may change the meaning of the whole mathematical text. Here spatial relationships are precise and always significant, because they represent numerical relationships among the data. In fact in a Cartesian graph, *only* the spatial relationships between elements have meaning. The elements are points that have no characteristics other than position on the plane.

A scientific graph is an utterly systematic form of picture writing. The scientist may see in the graph an organizing principle that was not apparent in the column of numbers from which the graph was generated. It may seem obvious that a graphic representation reads more easily than a column of numbers, but experimental scientists in the 17th and 18th centuries came to this realization more slowly than Descartes himself might have hoped. A number of mechanical devices were invented—weather clocks, automatic barometers, tide recorders—that produced line graphs as they measured. Yet scientists often took these graphs and converted them back into numerical tables for analysis. (Beniger & Robyn, 1978, p. 2) The late 18th and the 19th centuries saw the first systematic use of graphs to represent and analyze data from the world.

Today the graphic writing space is fully established: there is often no quicker or more reliable way for a scientist to examine intelligently (that is, to "read") the massive number of measurements that his or her computer-controlled instruments can record. The drawing of these diagrams is itself automated: computers collect the data and then plot them according to the viewer's requirements. In examining these graphs, scientific readers are looking for both patterns and exceptions, and the trick is to make both visually apparent. Thus computers can be programmed automatically to reduce "noise" or to produce maps in exaggerated colors to give a clearer sense of contrasts.

Such automated graphs and maps in the computer have readers, but no single, identifiable writer. The plotting programs are written by human beings, but the data are supplied by instruments whose function is to record such natural events as electromagnetic radiation, sound or pressure waves, and temperature. Often the instruments are attached directly to computers that record and store the measurements. No doubt many scientists believe that their graphs are natural writing or nature's writing—that human beings are reading what nature itself has produced. Human scientists can read nature's writing because they have mastered the mathematical language of nature. Without the numbered writing space, this natural writing cannot be recorded or understood. But it is precisely that requirement that makes the human scientist more than a passive reader. The scientist not only reads the graphic results; he or she also determines the variables to record and the way in which those variables will parameterize the writing space. Even in the simplest graph the scientist determines what the x and y axes will mean and what scale each will have.

Scientific picture writing is itself a process of discovery. The writer determines the parameters of the space and then lets the instruments do the writing. And even with the most sophisticated program, some human writer, programmer, or scientist must still decide how the writing space will be numbered. He or she may renumber the space many times to see the data from different perspectives. Scientists do not in general know what pattern their data will produce, and in fact they change perspectives in order to see something they have not anticipated or could not see clearly from another view. The computer can be effective here precisely because it allows rapid reworking of the space. In scientific graphing, the writer and reader are often the same scientist or team of scientists, and the irony is that such writers do not know in advance what they will be giving themselves to read. Here the scientific picture writer resembles the verbal writer, who may also be surprised by the text he or she produces. Scientific graphic writing, particularly with the aid of the computer, distances writers from their writing (data) in such a way that the writing no longer seems to belong to them at all. We might compare this situation to the automatic or trance writing practiced at various times in history, most recently by the surrealists. But in those cases the goal was to lose control, to annihilate the conscious censor and allow unconscious images and ideas to pour forth. In the automatic writing of science, a layer of computerized control is imposed between the world and writing space. The space itself is disciplined by the numbering scheme imposed on it.

Graphic Rhetoric

Although the numbered graph was and is an alternative to verbal writing, the barrier between the graph and the textual writing space has never been absolute. Even a pure Cartesian graph has its axes labeled with letters of the alphabet. The history of graphic design and typography shows that in the best graphs the numbered space and the verbal space not only coexist, but also interpenetrate. The statistical graphs of the 18th and 19th centuries contained a fair amount of writing, which served to anchor the graph to the verbal writing space. Edward Tufte, a contemporary writer on graphics, still advises that graphs should be combinations of words, images, and numbers and adds that "[d]ata graphics are paragraphs about data and should be treated as such" (Tufte, 1983, p. 181). He means that graphs should be integrated into the text so that the reader's eye moves easily from a paragraph of words to the graph and on to more words. The free combination of words, numbers, and images that is characteristic of the electronic writing space did not begin with the computer; it has been a feature of the best graphics of the last two centuries.

Scientific graphs combine the oldest and the newest of languages—picture writing and modern mathematics—and the result is a rhetoric that our culture finds most convincing. To make modern science palatable to a general audience, it seems that most of the mathematics must be translated into words or pictures. One pretty result is the mathematically defined pseudopicture, in which equations rather than tangible objects create the lines and shadings. Thus, mathematical objects called Mandelbrot sets can be made in surreal landscapes—a mountain lake or steep cliffs beside a placid sea. The point is to trick the viewer into putting the image in the wrong category, regarding it as an object in pictorial space drawn after nature, rather than as a graph. Programmers play this game perhaps out of a concealed desire to demonstrate that mathematics underlies the world. The Pythagorean impulse to construct the world from numbers comes naturally to anyone who builds or programs computers.

Experts in computer graphics have learned how to generate all sorts of recognizable forms mathematically and to give their forms a three-dimensional presence. Their aim is to enable the machine to create images that look as if they came from the world of light. For example, the images in Fig. 47.3 were generated from a data structure that was itself based on a series of photographs. Once the computer has turned these photographs into a mathematical structure of points and shadings, it can manipulate that structure to generate a variety of images with different lighting and from different perspectives. The machine can create an animation in which the viewer's perspective changes as he or she walks through the building. Computer graphics such as these are vivid examples of the computer's ability to mathematize space: to bring numerical and pictorial space together.

Even without the computer, however, contemporary graphics seems dedicated to combining the picture with the scientific graph. One unhappy result is the pseudograph that

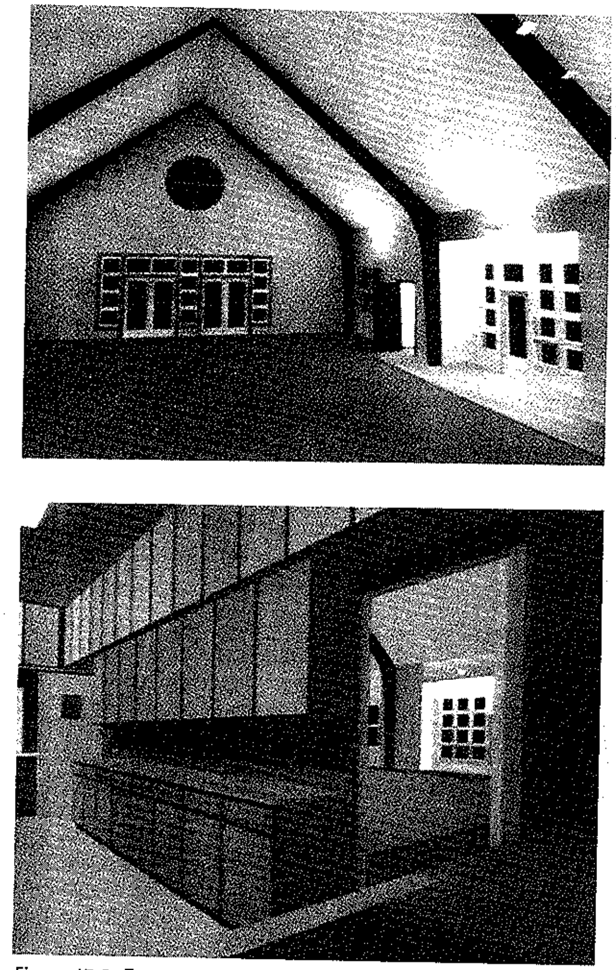

Figure 47.3. Two computer-generated images from the UNC Walkthrough project. Reprinted with the kind permission of Frederick P. Brooks, Jr., principal investigator, and John Airey, team leader. Orange United Methodist Church fellowship hall design by Wesley McClure, FAIA, and Craig Leonard of Böhm NBBJ.

is now common in newspapers, magazines, and television. Here the numbering of the space is so reduced that it becomes a decoration for rhetorical effect, and the graph resolves itself into naturalistic forms, like a degenerating tradition of art or architecture. A graph showing the increase in airline ridership over the past ten years will feature a passenger jet zooming up to the right over a Cartesian grid, its exhaust trail defining the increase year by year. A bar chart of industrial pollution will have colored smoke stacks to indicate the values of each pollutant. A pie chart on snack food in America will take the form of a real pie. These are graphs seeking to return to their roots as pure iconic picture writing, in which images float free in a continuous and unnumbered space. Perhaps the descent from the great visual rhetoric of the 19th century to the pseudographs of today's newspapers mirrors the decline in verbal rhetoric in the same period. In any case, in this final era of print technology, designers of books, journals, and newspapers mix words, images, and diagrams without restraint. The result is sometimes successful, sometimes a parody. Graphs take on grotesque shapes in order to reflect their subject matter. Diagrams sometimes intrude in the verbal text itself, as illustrations did with greater artistry in the Middle Ages. Conventional lined text is superimposed on diagrams, so that the diagrams seem to be a prisoner of the text to which they refer. The pure verbal writing space, the implicit ideal of print technology, now penetrates or is penetrated by the pictorial space of the image and the numerical space of the graph.

At its worst, the printed page often seems exhausted—as if it were trying to convince itself of its own vitality with riotous displays of color and form. At its best, however, print is anticipating the new visual rhetoric of electronic writing, in which words, images, and numbered elements easily occupy a single space. On a bit-mapped computer screen, every pixel is an element in a two-dimensional Cartesian graph: letters of the alphabet are themselves graphic lines and curves. The whole visual space of the screen is numbered by its x and y coordinates, and the computer can draw text at any coordinate position. It can also give over any position to a graphic. It is therefore natural to include numerical graphs on the screen along with the text, just as it is natural to include digitized pictures and icons. Sedate rows of linear text are becoming the exception rather than the rule. Instead alphabetic text may be anchored anywhere on the screen—beside, above, or below picture elements. The numbered space also serves as a grid to control the movement of graphs and diagrams. The computer can plot lines of data before the reader's eyes. It can present, for example, political maps that change to reflect the passage of years or centuries—a technique that until recently was limited to film or video with hand-drawn animation. The computer makes possible a kind of historical atlas in which invasions and battles, colonization, and the growth of populations and cities are shown in time as well as space.

The authors of such an atlas will have to learn to work in a new dimension. Designing for the printed page, they must consider how to turn historical change into a readable, static picture—how to place timelines, lines of march, and dates on the map in a readable way. An electronic map will have to be readable even as it changes; the authors must conceive of their map as a temporal experience for their readers. The same holds for writers who seek to animate any verbal or graphic text in the computer. They must envision what the reader will see at each moment and how that view will accord with what comes before and after. Authors in print or manuscript must also conceive of their text as unfolding in time, but they have little control of the reader's pace. The electronic author who chooses to animate must bear greater responsibility for the reader's temporal experience, because he or she can regulate the flow of text and images on the screen.

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