The Semiotics of the Digital Image

Patricia Search

ABSTRACT

Western formalism and postmodernist theory do not provide an adequate framework for interpreting many forms of digital art. Using artwork from the 1950s to the present, the author shows how the semiotic structure of the digital image defines a new visual aesthetic in which symbols become interpretations of symbols, and multiple levels of graphic encoding take on discursive characteristics similar to linguistic syntax. The author examines the semiotics of the digital image within the context of philosophical developments in mathematics and science.

Contemporary art criticism is deeply rooted in modernist and postmodernist theories. Modernism, which drew on the formalist theories of artist Ad Reinhardt and critic Clement Greenberg, was a period of art-for-art's-sake that called for "pure painting" that was free of "illustration, distortion, illusion, allusion or delusion"[1]. For Reinhardt and Greenberg, the physical dimensions of the medium defined "pure painting" and "pure sculpture." Modernist artists such as Reinhardt stripped their paintings of three-dimensional (3D) illusions and embarked on academic studies that emphasized "the flat surface, the [rectangular] shape of the support, the properties of pigment" [2]. This aesthetic gave rise to abstract expressionism, color-field painting and minimalism.

With his formalist theories, Greenberg sought to establish objective criteria for the evaluation of art based on the interaction of form and medium. Modernist theory, however, was highly deterministic, with only one approach to evaluating the aesthetic quality of artwork.

As formalism reached a peak in the 1960s, body, performance, pop and conceptual art rejected the modernist doctrine and ushered in the era of postmodernism, which challenged all restrictions on form and aesthetics. For many theorists, the fragmented pluralism of postmodernism led to ". . . depthless styles, refusing, eluding, interpretation" [3].

Out of this aesthetic chaos, new forms of art emerged, including works that use computer graphics as an integral part of the design process. However, much of this art is criticized for its lack of aesthetic quality, with critics maintaining that the work merely imitates earlier art forms. In many instances, the critical theories of modernist and postmodernist discourse define these evaluative criteria. Reminiscent of the modernist doctrine, many writings highlight characteristics of the digital medium—such as kinetics, interaction and networking, simulation, virtual reality, and numerical analysis—as the principle criteria for defining and evaluating the aesthetics of digital art. Critics often misinterpret works that do not exhibit these attributes as artwork that could have been done in another medium without the use of electronic technology.

This approach to evaluating digital art overlooks the semiotics of the digital image, in which symbols become interpretations of symbols, and multiple levels of graphic encoding take on discursive characteristics similar to linguistic syntax. As this conceptual environment of symbols and text replaces tactile and kinesthetic interaction with the artwork, new forms of creative expression codify form, space, action and time into diverse levels of abstraction. Unlike the fragmented visions of the postmodernist period, these works merge discrete concepts into fluid, integrated statements.

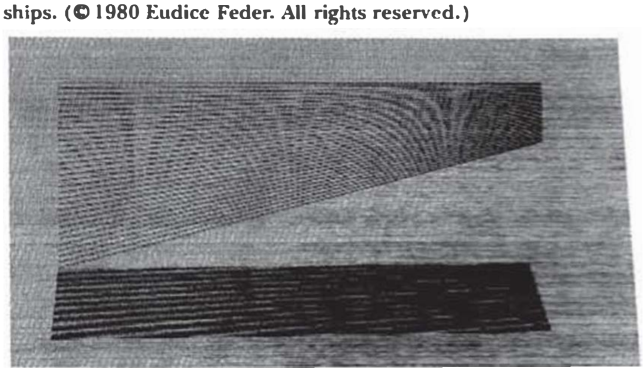
This paper examines the semiotics of the digital image within the context of philosophical developments in mathematics and physics. In these fields, causality and deterministic logic have been replaced by "descriptive" mathematics and scientific theories of relativity and quantum mechanics. The concepts behind these new scientific models of reality are also an integral part of the semantic-syntactic structure of the digital image.

The Visual Logic of Descriptive Geometry

Geometry is one of the oldest branches of mathematics and the architectural framework for computer graphics. The term *geometry* is derived from Greek words meaning "earth measurement," and early Euclidean geometry used deductive methods to study flat surfaces (plane geometry) and rigid 3D objects (solid geometry). These linear, static methodologies were based on sets of unproven assumptions called axioms, which were derived from perception and experience [4].

Mathematicians gradually realized that if these intuitive assumptions were replaced by abstract terms devoid of preconceived meaning, the resultant type of formal system would provide a more flexible structure for evaluating spatial relationships. In 1637, Descartes developed a branch of analytical

Fig. 1. Eudice Feder, *Separation*, Calcomp plot, 12 × 18 in, 1980. Artists such as Feder use precisely controlled linear modulations, rather than perspective projections, to define spatial relationships. (© 1980 Eudice Feder. All rights reserved.)



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geometry that used algebraic equations to visualize points, lines and forms, thus raising the study of geometry to a new level of abstraction by detaching it from its perceptual base. However, Cartesian geometry, like Euclidean geometry, was still founded on deterministic logic and deductive reasoning.

The 1800s brought new philosophical and scientific inquiries into the relationship between optical truth and interpretation. Mathematicians reevaluated traditional assumptions about space. New theories evolved that further underscored the need for geometric systems that were not based on the intuitive perception of space and time. In 1854, for example, a German mathematician named Georg Riemann postulated that space could be curved—a theory that Einstein later used to develop relativity. Riemann's research, along with the work of other mathematicians in the nineteenth century, required new methods of defining and visualizing spatiotemporal concepts. The linear determinism of Euclidean geometry was slowly replaced by mathematical models that described multidimensional, abstract relationships. The dynamic interaction of these spatiotemporal descriptions was reflected in new mathematical terms such as *betweenness, translation, reflection, projective* and *inversive* models, and *hyperplanes*.

In the 1960s, with the help of computer graphics, mathematicians bridged the gap between symbolic descriptions and perception by using patterns to visualize logical processes and simultaneous relationships. Mathematician Lynn Steen describes mathematics as a "science of patterns" with abstract levels of visual encoding in which "theories emerge as patterns of patterns" [5]. In this new descriptive geometry, perceptual references symbolize dynamic processes and interrelationships that change over time. Logical analysis is augmented by the perceptual, holistic synthesis of visual patterns. According to mathematician Jacques Hadamard, images are important to provide a "simultaneous view of all the arguments" [6].

The *visual logic* of descriptive geometry enables mathematicians to understand the structure of a problem and then reconstruct and improve their intuitive understanding of numerical relationships. Multiple levels of perceptual encoding create a model for describing "those aspects of visual modes of thought that appear to lie beyond the analogy of mere sight" [7]. Mathematicians can analyze the syntactical components of geometric space and then synthesize those relationships into an integrated system.

Metastructural Models in Physics

Like early Euclidean geometry, classical physics was built on deterministic logic and reductionist theories that limited the interpretation of physical forces to strict causation. Newtonian mechanics, for instance, was built on the reductionist theory that time and space were rigid and constant. Newton described time and space as follows:

> Absolute, True, and Mathematical Time . . . flows equably without regard to any thing external. . . . Absolute Space, in its own nature, without regard to any thing external, remains always similar and immovable [8].

According to classical physics, reality was an objective truth and the scientist was a passive observer looking on. However, in science, as in mathematics, theories of indeterminism eventually replaced the basic unit of Aristotelian logic, the syllogism, which is based on the "if—then" proposition. With the introduction of relativity and quantum physics, a new scientific model of the world emerged in which dynamic interactions replaced static, linear forces.

In his theories of relativity, Albert Einstein demonstrated that space and time are not absolute [9]. Both space and time are multidimensional forces that defy the limitations of perceptual interpretation. At the speed of light, for example, time encompasses both the present and the future. In effect, "time ceases to change because it contains all change" [10]. Spatial representations also merge at high speeds. As space is compressed, multiple views of objects are possible from a single perspective because planes and volumes become one [11].

Quantum physics continued to develop this pluralistic and highly abstract model of spatiotemporal interaction. Quantum theory emerged in 1900 when physicist Max Planck demonstrated that energy comes in discrete unit (rather than a continuum) called "quanta," a term derived from the Greco-Latin word for "how much" [12]. Traditional observations about the physical world broke down in the microscopic world of quantum mechanics. Scientists needed new theories to explain the indeterministic and highly interactive nature of subatomic units.

In 1926 Niels Bohr developed the theory of complementarity to describe the antithetical duality of physical forces that appeared in quantum physics [13]. Light, for instance, is *both* a *wave* and a particle. However, light reveals only one attribute at a time, and the scientist determines that attribute by the type of measuring device used in an experiment. Scientists also learned that multiple forces such as gravitation, nuclear forces, and electromagnetism can operate simultaneously in the same place [14]. In this multidimensional model, physicists discovered the "quantum leap," the fact that electrons can move between orbits and simultaneously appear in another orbit without traversing the intervening space [15]. The linear dimensions of strict causation that characterized classical physics were replaced by a matrix of interactive relationships.

The world of quantum physics raised as many questions as answers. There was no longer any such thing as "objective" reality. Relationships were defined by the participation and interpretation of the observer. Scientists and mathematicians of the time learned that they could no longer rely on intuition and experience to define physical forces. They needed to build a flexible, abstract framework for a virtual world with tentative truths.

The Semiotics of the Digital Image

Mathematicians and physicists demonstrated that we cannot rely on our perceptual interpretations as accurate descriptions of reality. Instead, we must raise our intuitive knowledge of space and time to a higher level of abstraction that defines the dynamics between human perception and reality. Once we identify these interactive forces, we can create multidimensional models that integrate mathematical laws and interpretation into virtual extensions of the physical world.

Psychologists call this process of redefining perceptual knowledge "reflective abstraction." Computers have made it easier for mathematicians, scientists and artists to use this process to visualize and construct new knowledge beyond the boundaries of logic and expectation. In digital art, the result is a new visual aesthetic that echoes the philosophical perspectives of modern mathematics and physics in several semiotic structures:

- Metastructural Dynamics
- Cognitive Mapping
- Visual Logic.

This paper discusses each of these dimensions of the digital image and cites examples of representative artwork [16].

Metastructural Dynamics

In computer graphics, terms such as *3D model*, *rendering* and *simulation* suggest an artificial retreat from reality. However, artists actually use these techniques to visualize scientific interpretations of reality by creating metastructural environments that expand the intuitive dimensions of space and time into abstract models of a dynamic, virtual world.

Using an architectonic system of mathematically defined forms, colors, compositions and perspectives, an artist can control the hierarchy of geometric relationships and redefine the geometric syntax of experiential space and time. The use of geometric coordinates to specify spatial relationships has shifted the artistic focus to linear and surface projections rather than perspective projections. Working with subtle changes in attributes of lines such as width, color, texture and position, artists transform the planar dimensions of linearity into volumetric extensions of space. This type of "linear space" is an integral part of works by artists such as Edudice Feder (*Separation* [1980]; *Permutations* [1980]; *Wind-Warn* [1985]), Herbert Franke (*Serie 1956* [1956]; *Grafik I* [1956]), and A. Michael oll (*Ninety Computer-Generated Sinusoids with Linearly Increasing Period* [1965]). These artists use precise, geometrically controlled lines to create multiple levels of perceptual space (Fig. 1). Tony Longson's work adds a physical dimension to this concept of linear space. Longson creates line and "tonal" drawings on multiple panels of Plexiglas, then overlaps the panels to create 3D constructions (*Group Theory Grid* [1968]; *Square Tonal Drawing #2* [1980]).

For other artists, surface rather than linear projections shape the metastructural dynamics of space and time. In *Untitled* (1975) by Manuel Barbadillo and in Vera Molnar's series *Hypertransformations* (1973–1976), geometric progressions define randomly shaped, interlocking planes of color with ubiquitous perspectives and orientations (Fig. 2). In these works, the two-dimensional (2D) space becomes all-inclusive and folds into itself, much in the way that the curved space of modern geometry and physics does.

The medium of light in computer graphics also transforms the spatial dimensions of lines and planes. For example, in works by Ben Laposky (*Oscillon 40* [1952]; *Oscillon* [1956]) and Kathleen Dolberg (*Gossamer* [1984]), transparent filaments of light create flowing shapes that engulf the surrounding space and blur the perceptual boundaries between lines, surfaces, 3D space and infinity. The medium of light also defines different levels of linear and surface space in the "virtual sculptures" of Michael O'Rourke. In images such as *Manhattan Invitation* (1987), O'Rourke creates a visual interplay between light and space by juxtaposing definitive geometric lines and objects with diffuse areas of modulated colors (Fig. 3).

The reflective and refractive qualities of light also enable artists to visualize the spatial relationships *in* and *between* objects. In Yoichiro Kawaguchi's animations (*Origin* [1985]; *Ocean* [1988]), highly reflective and transparent surfaces display the surrounding environment, transforming organic forms into mirrored visions of space within space. The images embrace space and time from all directions, rather than limiting the vantage point to a unique perspective. Space becomes all-inclusive and *n*-dimensional, as in the works of Barbadillo and Molnar.

Time—in particular, the spatial representation of time—establishes a conceptual link between the physical and virtual dimensions of these metastructural models. Time is defined as an infinite extension of space and form through the mathematical abstraction of lines, angles and curves. The geometric syntax of the fractal image is an excellent example of this temporal link between the physical and virtual dimensions of reality. In other artwork, such as Kawaguchi's art, time is defined by reflective and transparent objects that visualize the passage of light through space. In these images, layers of visual data define multidimensional arrays that visualize simultaneous and sequential levels of spatiotemporal perception.

The metastructural dynamics of the digital image integrates structure and control into a spatiotemporal continuum that defines an infinite, virtual space. This visual dichotomy is especially evident in artwork that juxtaposes the definitive geometry of 3D objects with subtle gradations of texture, color, transparency or reflection. The computer paintings of David Em (*Redbal* [1980]; *Zotz* [1985]) and my own artwork (*Gossamer Lights* [1986]; *Coloratura 100* [1988]; *Kaleidoscope* [1992]) represent this type of visual model (Color Plate A No. 2). In these images, geometric objects anchor the work in the logical dimensions of space and time, while perceptual transformations challenge the limitations of experiential reality.

Cognitive Mapping

The mathematical models of descriptive geometry, relativity and quantum mechanics emphasize interactive webs of sequential and simultaneous events. In many forms of digital art, perceptual and cognitive processes define a matrix of temporal relationships, resulting in a complex network of associations.

In some artwork, this multidimensional structure visualizes the geometric syntax of space and time. Bruce Hamilton and Susan Hamilton, for example, use computer graphics to create conceptual drawings for sculptures like *Tetrad* (1984), *Metamorphosis III* (1987), and *Scarab* (1989). In these works, mathematically defined proportions create a geometric balance between lines, planes, textures and color (Fig. 4). The mathematical syntax of these sculptures not only visualizes logical, sequential processes, but also provides a syntactic filter for simultaneously mapping multiple perspectives in space and time.

Other artists use a dynamic, visual-linguistic syntax to construct interactive webs of associations. In *Random Ransom* (1986) and *Indicted Invited* (1988), Tom Leeser extracts images and text from their original sources and integrates them into a "media archeology" that challenges their original meanings and context [17]. Paul Berger creates digital photographs that visualize the cognitive networks of information in a database. In works like *Print-Out* (1988), Berger uses photocopied lists of database entries as backgrounds for photographic portraits [18].

In interactive works of art, narrative intention increases the complexity of cognitive mapping. The viewer expects to construct meaningful relationships and must continually redefine the webs of interaction between expectations and reality. Abbe Don explores these issues in *We Make Memories*, an interactive program that allows viewers to create stories by experimenting with the associative links between content, structure and context [19].

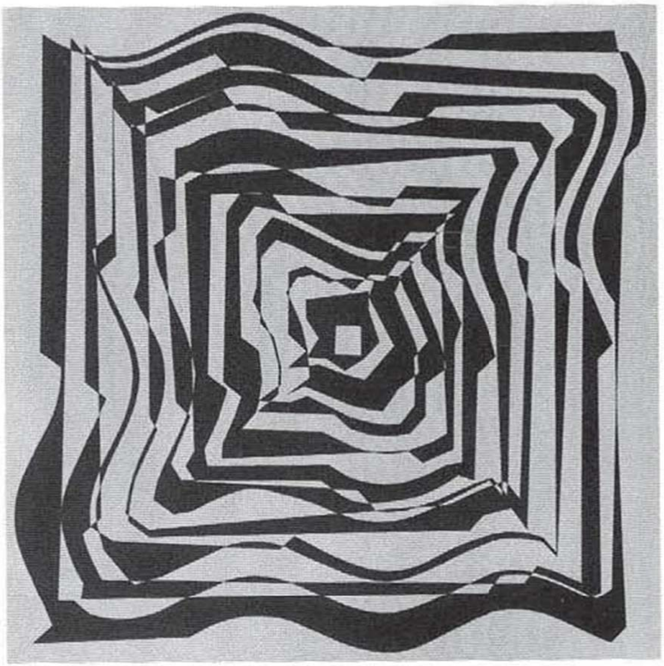


Fig. 2. Vera Molnar, *Hypertransformations*, silkscreen, 20 × 20 in, 1974. In Molnar's prints, geometric progressions transform two-dimensional planes into interlocking spaces with multiple orientations. (© 1974 Vera Molnar. All rights reserved.)

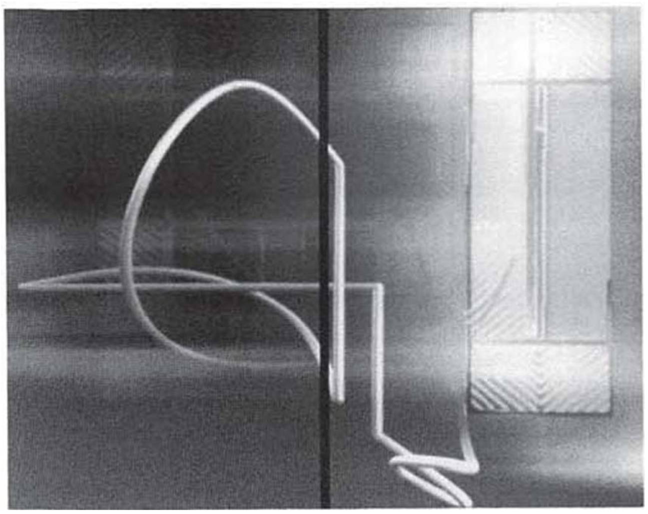


Fig. 3. Michael O'Rourke, *Manhattan Invitation*, diptych/ Cibachrome transparencies, 48 × 60 in, 1987. By integrating geometric lines and objects with diffuse areas of colored light, O'Rourke creates "virtual sculptures" that expand the dimensions of linear and surface space. (© 1987 Michael O'Rourke. All rights reserved.)

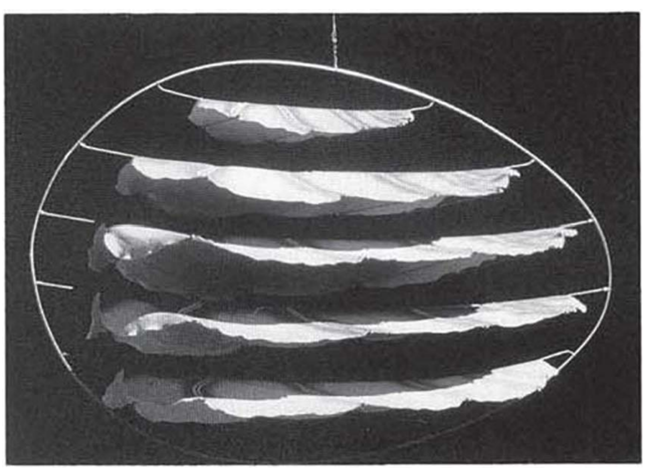


Fig. 4. Bruce Hamilton and Susan Hamilton, *Scarab*, 29 × 50 × 19 in, 1989. In the Hamiltons' sculptures, balance and proportion create a geometric syntax that defines simultaneous relationships in space and time [32]. (© 1989 Bruce Hamilton and Susan Hamilton. All rights reserved.)

In the digital work, a semantic-syntactic network of images, text and sound directs actions and expectations. The viewer constructs a system of relational codes that becomes an integral part of the interpretation of the work. Multiple levels of perception and cognition may exist within individual symbols. James Johnson, for instance, creates artists' books that make use of symbols that integrate visual and linguistic semiotics. Using computer graphics, Johnson designed a "Skeletons" font, which is derived from silhouette drawings of skeletons. In the book *Dead Air* (1991), he uses this font to form words that complete phrases beginning with the word "dead," such as dead wrong and dead last [20]. Another of his books, entitled *Index* (1992), maps pictures of unusual objects to individual letters of the English alphabet. Johnson uses this pictographic alphabet to create visual compositions that are "subject to verbal structures" [21]. The title of each composition indicates the corresponding verbal meaning (Fig. 5).

The work of artist Jim Rosenberg adds another level of inquiry to these visual-linguistic maps. He uses "word clusters" to experiment with the syntax of words that occupy the same point in logical and physical space. In his interactive program *Intergrams* (1990), a group of phrases is indecipherable when the phrases overlap each other in the same space. However, moving the computer mouse over the cluster discloses individual phrases and hides the remaining ones, revealing the meaning of the cluster [22].

The use of symbols to map perceptual and cognitive associations is an important dimension in the semiotics of the digital image. Like recursive patterns in mathematics, symbols become interpretations of symbols. Thorne Shipley conducts theoretical research in "pattern and matrix vision" [23]. His work investigates the different levels of perception and cognition that are defined by visual patterns or textures in linguistic messages. Unlike Johnson, who maps synonymic associations between words and images, Shipley is exploring what he terms "heterological message duality" or "message multiplicity" [24]. He illustrates this concept using words that are typographically constructed from other words. For example, in one of his illustrations, the text for the word "yes" is repeated in a pattern that forms the shapes of the letters in the word "no." Similarly, the text for the word "you" forms the shape of an "I," and the word "will" creates each of the letters in the word "won't." When these typographical constructions appear in phrases such as "No, I won't," the visual patterns within each word communicate a secondary message—"Yes, you will" [25].

Future research and investigation will expand the semantic-syntactic dynamics of these types of cognitive maps. As artists continue to explore the potential of interactive multimedia in artwork, they will find new ways to add levels of sensory interaction to the layers of relational encoding that exist in these cognitive maps. Artists will also learn how to integrate the linguistic patterns of user interfaces and programming languages into visual symbols, adding still more interpretive links to the semiotic structure of the digital image.

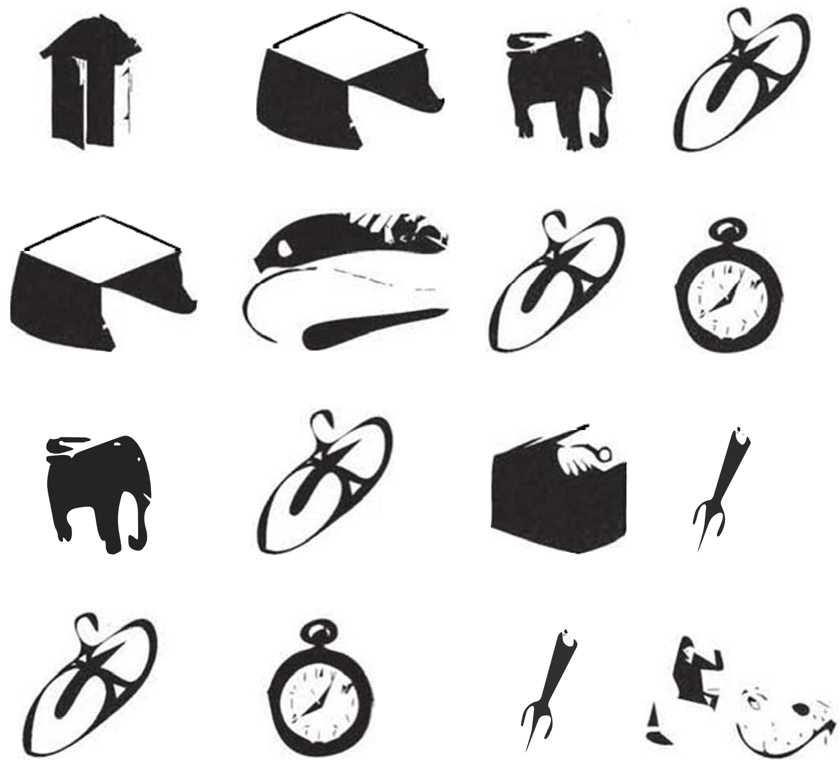


Fig. 5. James Johnson, *LineIdeaNetsEasy*, laser print, 1994. Mapping symbols to letters of the English alphabet, Johnson creates compositions that integrate visual and linguistic semiotics. (© 1994 James Johnson. All rights reserved.)

Visual Logic

Just as writing fostered the development of abstract thinking with the implementation of symbols and sounds to designate thoughts, the mathematical syntax of computer graphics defines 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.

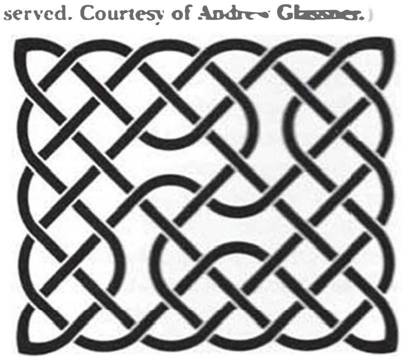
Artists, like mathematicians and scientists, use visual patterns to improve their intuitive understanding of logical and perceptual relationships. Many artists, for example, use computer graphics to investigate the logical and intuitive dimensions of design. The grid, which postmodernists rejected as a symbol of structural control, has resurfaced as an intuitive symbol of the underlying structure of spatiotemporal procedures. Daniela Bertol's collage *Bending and Twisting: Hypothesis #3* (1988) uses a twisted geometric grid to visualize the algorithmic dynamics of space and time. The grid is also an integral part of Andrew Glassner's *Celtic Knot* series (1986), black-and-white drawings that investigate the geometry and form of Celtic knot weaving (Fig. 6). Glassner uses an invisible grid to create a visual pattern that symbolizes the spatiotemporal relationships involved in the perception and comprehension of this intricate weaving procedure.

Some artists use design techniques to create a multidimensional syntax that articulates the interaction of perception and cognition. For more than 20 years, Manfred Mohr has been using computer graphics to analyze the relationships of lines in the cube. Mohr uses the 12 lines that make up a cube to create a new visual language that "disrupts the symmetry of the cube" [26]. In prints and paintings such as *P-26/2 Inversion Logique* (1969), *P-155 Cubic Limit* (1974–1976), and *P-306 Divisibility I* (1980–1983), individual lines form discrete units of information and define a visual syntax that signifies the sequential steps in the perception of geometric forms and space. At the same time, Mohr's designs form an integrated whole in which black and gray lines establish contrasting layers of perceptual events that disrupt the sequentiality and order of the mathematical logic.

Artists also use the visual logic of computer graphics to explore the intuitive synthesis of logical events. By juxtaposing text and images that symbolize procedures or actions with images that represent the end results of those actions, the artist constructs an interpretive dialogue that visualizes the temporal transformation of ideas. For Colette Bangert and Charles Bangert, this dialogue begins with the development of computer-graphics software. In works like *Large Landscape: Ochre & Black* (1970), *Grass Series* (1979–1983), *Circe's Window* (1985) and *Katie Series* (1986–1987), the Bangerts use original software to translate mathematical models into lines and forms in space (Fig. 7). The software enables them to explore the relationships between algorithmically defined numerical functions and the drawing process: "At the time the programs were written, we thought of the transforms and the interactions of the instances. Now we think of the whole drawing as a picture of a single line in a high dimensional space" [27].

Margot Lovejoy uses mathematical symbols to visualize the roles that perception and logic play in the interpreta-

Fig. 6. Andrew Glassner, *Celtic Knot Study I*, phototypesetter plot, 1986. In his *Celtic Knot* series, Glassner uses computer graphics to visualize the logical and intuitive dimensions of process and procedure. (© 1986 Xerox Corporation. All rights reserved. Courtesy of Andrew Glassner.)



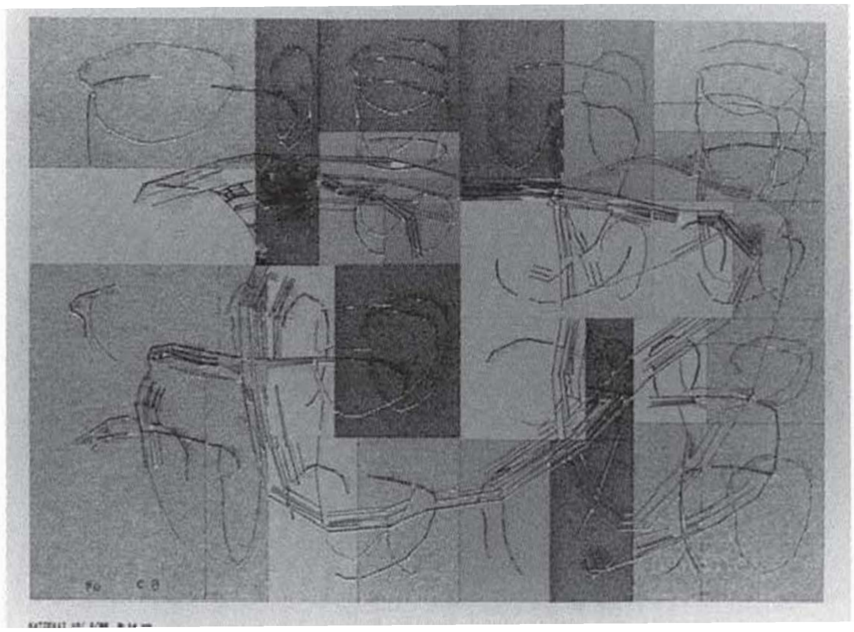


Fig. 7. Colette Bangert and Charles Bangert, *Katie Series: Field Greyed*, computer plot, colored inks on paper, 8 ½ × 11 in, 1986. The Bangerts use mathematical algorithms to explore the underlying structure of line and form. (© 1986 by Colette Bangert and Charles Bangert. All rights reserved.)

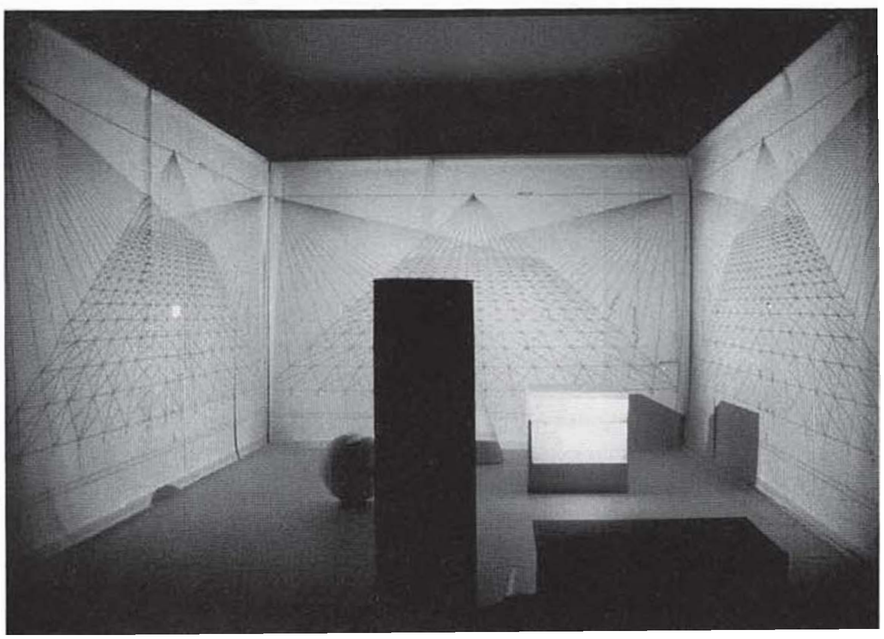


Fig. 8. Margot Lovejoy, *Azimuth XX*, projection installation, 12 × 12 × 8 ft, 1986. By juxtaposing two-dimensional representations of space with three-dimensional objects, Lovejoy visualizes the logical and intuitive dimensions of spatiotemporal perception. (© 1986 Margot Lovejoy. All rights reserved.)

tion of space. In 2D works such as *Azimuth I* (1983) and *Azimuth II* (1983), geometric shapes, angled lines and architectural drawings create a visual syntax that signifies the perceptual and cognitive processes involved in the interpretation of 2D representations of space. Lovejoy's 3D installations integrate physical space and time into the visual logic of spatial perception. *Azimuth XX* (1986), for example, juxtaposes 3D geometric forms existing in "real" space and time with 2D projections of linear perpective grids (Fig. 8). Lovejoy describes her work as "the truggle to control, represen t, and construct meaning in the 'gap between art and life'"[28].

The visual logic of the digital image is highly modular. Visual symbols can be rearranged to create new syntactical relationships. Digital images can assume many characteristics of linguistic syntax without jeopardizing their perceptual immediacy. The high level of abstraction in this visual system transcends the constraints of verbal language. The visual logic of the digital image shares many of the conceptual attributes of "metaphorms," visual metaphors that Todd Siler creates to describe the temporal and procedural relationships between objects or ideas. For example, Siler uses the following metaphorms to symbolize the complementary relationships between art and science: parallel lines, spirals, intersecting planes and woven fabric. Siler defines a metaphorm as a "means of implying the likeness between things," and he describes the power of metaphorms as follows:

> In metaphorming something, we can traverse the constraints of logic and verbal thought, transferring or relating from one object to another a new meaning, pattern, or set of associations. Like the language of pure mathematics, which can describe abstract *n*-dimensional processes and forms, the symbolic language of metaphorms is also multidimensional. It operates simultaneously on many planes of associations, nuances, and meanings [29].

CONCLUSION

Modern mathematics and physics demonstrated that we need to develop abstract models of reality that are flexible enough to accommodate the shifting dynamics of a wide range of variables, including the subjective decisions and interpretations of the observer. In order to build flexible models that can change with new perspectives and observations, we need to understand differences as well as interactive relationships between these variables. As Marvin Minsky points out in *The Society of Mind,*

> We usually like to think in positive terms about how various parts of systems interact. But to do that, we must first have good ideas about which aspects of a system do *not* interact. . . . In other words, we have to understand *insulations* before we can comprehend interactions [30].

For mathematicians, scientists and artists, computer graphics provides a powerful tool for visualizing the insulations *and* interactions of a multidimensional system. The digital image integrates the structural control of analytical processes with the holistic powers of perception and interpretation. Artists are abandoning the predictable, deterministic logic of the modernist period and the random, irrational infrastructures of post-modernism. In the digital image, the geometry of mathematics and the logical syntax of programming languages create a conceptual framework for synthesizing complex webs of interactions.

In the future, new technology will alter the semiotics of the digital image. High-definition television, for example, will modify established perceptions in space and time. High-resolution displays will place an added emphasis on detail and text and increase the prominence of background imagery. As the size of digital displays approaches the scale of actual walls, the syntactic structure of the image will become an integral part of the surrounding architectural space. In addition, the electronic dissemination of art, coupled with interactivity and collaborative networking, will increase the temporal dynamics of the digital image.

All of these developments further mandate the need for a new design discourse—perhaps based on an interactive audiovisual language—that reflects the dynamic structure of the digital image. 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. Models of reality, defined by abstract descriptions of tentative truths, are subject to constant reevaluation. The ensuing dialogue between logic and perception leads to an eternal quest for new perspectives—a quest that Minsky describes as the interaction of two types of complementary knowledge: "We search for 'islands of consistency' within which ordinary reasoning seems safe. We work also to find and mark the unsafe boundaries of those domains" [31].

The semiotic structure of the digital image visualizes these complementary forces and helps us understand the limitations of perception and reason, thus enabling us to transform those "unsafe" boundaries into new knowledge and insights about the complex world around us.

References and Notes

1. A. Reinhardt, *Ad Reinhardt*, exh. cat. (New York: Betty Parsons Gallery, 1947) n.p.

2. C. Greenberg, "Modernist Painting," *Arts Yearbook* 4 (1961) pp. 103–104.

3. I. Hassan, "Pluralism in Postmodern Perspective," in C. Jencks, ed., *The Post-Modern Reader* (London: Academy Editions, 1992) p. 197.

4. There were five Euclidean axioms: (1) Things that are equal to the same thing are also equal to one another; (2) If equals be added to equals, the wholes are equal; (3) If equals be subtracted from equals, the remainders are equal; (4) Things that coincide with one another are equal to one another; (5) The whole is greater than the part. See C. Reid, *A Long Way from Euclid* (New York: Thomas Y. Crowell, 1963) p. 27.

5. L.A. Steen, "Science of Patterns," *Science* 240, No. 4, 611–616 (1988)

6. J. Hadamard, *The Psychology of Invention in the Mathematical Field* (New York: Dover, 1915; 1954) p. 77.

7. T.G. West, *In the Mind's Eye* (Buffalo, NY: Prometheus Books, 1991) p. 209.

8. I. Newton, *Principia: The System of the World* (Berkeley, CA: Univ. of California Press, 1934) Vol. 1, p. 6.

9. Einstein developed two theories of relativity: (1) the special theory of relativity (1905), which described the electrodynamics of moving systems and (2) the general theory of relativity (1915), which described gravitational force.

10. L. Shlain, *Art and Physics: Parallel Visions in Space, Time and Light* (New York: William Morrow, 1991) p. 125.

11. Shlain [10] p. 127.

12. T. Ferris, *Coming of Age in the Milky Way* (New York: William Morrow, 1988) p. 286.

13. Shlain [10] p. 23.

14. Ferris [12] p. 293.

15. Ferris [12] p. 288.

16. Many of the works cited in this paper can be found in ACM SIGGRAPH Art Show Catalogs and ACM SIGGRAPH Art Show Slide Sets.

17. M. Lovejoy, *Postmodern Currents* (Ann Arbor, MI: Univ. of Michigan Research Press, 1989) p. 154.

18. Lovejoy [17] p. 190.

19. A. Dorn, "*We Make Memories*," *Leonardo* 24, No. 1 (1991) p. 88.

20. J. Johnson, "*Skeletons*," *Leonardo* 25, No. 1 (1992) p. 94.

21. J. Johnson, *Artist's Books*, bookwork catalog (Boulder, CO: James Johnson, 1993) n.p

22. J. Rosenberg, "Diagram Poems, Intergrams," *Leonardo* 24, No. 1 (1991) p. 90

23. T. Shipley, "Pattern Processing: A Further Rationalization of Sight," *Leonardo* 8, No. 1, 27–39 (1974).

24. T. Shipley, "Visual Textures as Impressionistic and Linguistic Messages: The Communication of Aesthetic, Scientific and Stylistic Information," *Leonardo* 26, No. 2 (1993) p. 127.

25. Shipley [24].

26. A. Seidman, *Printmaking: At the Speed of Thought*, exh. cat. (Philadelphia, PA: The Print Club, 1989) n.p.

27. Seidman [26] n p

28. P. Prince, "Things to Come," in *The Second Emerging Expression Biennial: The Artist and the Computer*, exh. cat. (Bronx, NY: The Bronx Museum of the Arts, 1987) p. 7

29. T. Siler, *Breaking the Mind Barrier* (New York: Simon and Schuster, 1990) p. 31.

30. M. Minsky, *The Society of Mind* (New York, Simon and Schuster, 1986) p 319.

31. Minsky [30] p. 277.

32. For a full-color reproduction of this illustration, see *Digital Image—Digital Cinema*, SIGGRAPH '90 Art Show Catalog, Supplemental Issue of *Leonardo* (1990) p. 97

Glossary

axiom—a self-evident proposition or rule that does not require demonstration or proof.

betweenness—in geometry, a relation connecting certain sets of three points. That is, given that points A, B and C are in "the relation of betweenness," it is possible to define various relationships concerning A, B, C, in which B is a point between A and C. For example, ABC may be points on lines AB and BC that are perpendicular to each other, in which case B will always be *between* A and C.

descriptive geometry—the use of pictures or diagrams, as opposed to algebraic or arithmetic methods, to visualize spatial relationships.

hyperplanes—a figure in hyperspace (space with more than three dimensions) corresponding to a plane in 3D space.

inversive mode—in geometry, figures derived from the use of inverse functions (two mathematical operations that can be performed in succession on a quantity to reproduce that quantity).

projective model—geometry that creates a one-to-one correspondence between the points and lines in two geometric figures.

reflection—in mathematics, a geometric relationship describing points equidistant from each other on either side of a line that is perpendicular to a given line

translation—the displacement of a point, line or object in space.