16

Abstraction and Complexity

Lev Manovich

What kind of images are appropriate for the needs of a global informational networked society—the society which in all of its areas needs to represent more data, more layers, more connections than the industrial society preceding it?[1] The complex systems which have become supercomplex;[2] the easy availability of real-time information coming from news feeds, networks of sensors, surveillance cameras—all this puts a new pressure on the kinds of images human culture already developed and ultimately calls for the development of new kinds. This does not necessary means inventing something completely unprecedented—instead it is apparently quite productive to simply give old images new legs, so to speak, by expanding what they can represent and how they can be used. This is, of course, exactly what the computerization of visual culture has been all about since it began in the early 1960s. While it made production and distribution of already existing kinds of images (lens-based recordings, i.e., photographs, film and video, diagrams, architectural plans, etc.) efficient, more importantly the computerization made it possible for these images to function in various novel ways by "adding" interactivity, by turning static images into navigable virtual spaces, by opening images to all kinds of mathematical manipulations that can be encoded in algorithms.

This short essay of course will not be able to adequately address all these transformations. It will focus instead on a particular kind of image, namely, software-driven abstraction. Shall the global information society include abstract images in its arsenal of representational tools? In other words, if we take an abstraction and wire it to software, do we get anything new and useful beyond what already took place in the first part of the twentieth century—when the new abstract visual language was adopted by graphic design, product design, advertising, and all other communication, propaganda, and consumer fields?[3]

After Effects

Let's begin by thinking about abstraction in relation to its opposite. How did the computerization of visual culture affect the great opposition of the twentieth century between abstraction and figuration? In retrospect, we can see that this opposition was one of the defining dimensions of twentieth-century culture since it was used to support so many other oppositions—between "popular culture" and "modern art," between "democracy" and "totalitarianism," and so on. Disney versus Malevich, Pollock versus socialist realism, MTV versus the Family Channel. Eventually, as the language of abstraction has taken over all of modern graphic design while abstract paintings have migrated from artists' studios to modern art museums as well as corporate offices, logos, hotel rooms, bags, furniture, and so on, the political charge of this opposition has largely dissolved. And yet in the absence of new and more precise categories we still use figuration–abstraction (or realism–abstraction) as the default basic visual and mental filter though which we process all images that surround us.

In thinking about the effects of computerization on abstraction and figuration, it is much easier to address the second term than the first. While "realistic" images of the world are as common today as they were throughout the twentieth century, photography, film, video, drawing, and painting are no longer the only ways to generate them. Since the 1960s, these techniques were joined by a new technique of computer-image synthesis. Over the next decades, 3-D computer images gradually became more and more widespread, gradually coming to occupy a larger part of the whole visual culture landscape. Today, for instance, practically all computer games rely on real-time 3-D computer images—and so do numerous feature films, TV shows, animated features, instructional videos, architectural presentations, medical imaging, military simulators, and so on. And although the production of highly detailed synthetic images is still a time-consuming process, as the role of this technique is gradually expanding, various shortcuts and technologies are being developed to make it easier: from numerous ready-to-use 3-D models available in online libraries to scanners that capture both color and shape information and software that can automatically reconstruct a 3-D model of an existing space from a few photographs.

Although computerization has "strengthened" the part of the opposition occupied by figurative images by providing new techniques to generate these images—and even more importantly, making possible new types of media that rely on them (3-D computer animation, interactive virtual spaces)—it has simultaneously "blurred" the "figurative" end of the opposition. What do I mean by this? Continuous developments in "old" analog photo and film technologies (new lenses, more sensitive films, etc.) combined with the development of software for digital retouching, image processing, and compositing eventually completely collapsed the distance that previously separated various techniques for constructing representational images: photography, photo-collage, and drawing and painting in various media, from oil, acrylic, and airbrush to crayon and pen and ink. Now the techniques specific to all these different media can be easily combined within the metamedium of digital software.[4]

One result of this shift from *separate representational and inscription media* to a *computer metamedium* is a proliferation of *hybrid* images—images that combine traces and effects of a variety of media. Think of a typical magazine spread, a TV advertisement, or a home page of a commercial website: maybe a figure or the face of a person against a white background, some computer elements floating behind or in front, some Photoshop blur, funky Illustrator typography, and so on. (Of course looking at the Bauhaus graphic design we can already find some hybridity as well similar treatment of space combining 2-D and 3-D elements—yet because a designer had to deal with the actual media, the boundaries between the elements of different media were sharply defined.)

This proliferation of hybrid images leads us to another effect—the liberation of the techniques of a particular medium from its material- and tool-specificity. Simulated in software, these techniques can now be freely applied to visual, spatial, or audio data that have nothing to do with the original media.[5] In addition to populating the tool palettes of various software applications, these virtualized techniques came to form a separate type of software—filters. You can apply reverb (a property of sound when it propagates in particular spaces) to any sound wave; apply depth of field effects to a 3-D virtual space; apply blur to type; and so on.

The last example is quite significant in itself: the simulation of media properties and interfaces in software has made possible not only the development of numerous separate filters but also whole new areas of media culture such as *motion graphics* (animated type that exists on its own or combined with abstract elements, video, etc.). By allowing the designers to move type in 2-D and 3-D space, and filter it in arbitrary ways, the development of After Effects Software has affected the Gutenberg universe of text at least as much if not more than Photoshop affected photography.

The cumulative result of all these developments—3-D computer graphics, compositing, simulation of all media properties and interfaces in software—is that the images that surround us today are usually very beautiful and often highly stylized. The perfect image is no longer something that is merely hoped for or expected in particular areas of consumer culture—instead, it is an entry requirement. To see this difference you only have to compare an arbitrary television program from twenty years ago to one of today. Just as the actors who appear in current TV shows, all images of today have been put through a plastic surgery of Photoshop, After Effects, Flame, or similar software. At the same time, the mixing of different representational styles which until a few decades ago was found only in modern art (think of Moholy-Nagy photograms or Rauschenberg's prints from 1960) has become the norm in all areas of visual culture.

Modernist Reduction

As can be seen even from this brief and highly compressed account, computerization has affected the figurative or "realistic" part of the visual culture spectrum in a variety of significant ways. But what about the opposite part of the spectrum—pure abstraction? Do the elegant algorithmically driven abstract images, which began to populate more and more websites in the late 1990s, have a larger ideological importance? Are they comparable to any of the political positions and conceptual paradigms that surrounded the birth of modern abstract art in the early 1920s? Is there some common theme that can be deduced from the swirling streams, slowly moving dots, dense pixel fields, mutating and flickering vector conglomerations coming from the contemporary masters of Flash, C++, Java, and Processing?

If we compare 2004 with 1914, we will in fact see a similar breadth of abstract styles: a strict northern diet of horizontal and vertical lines in Mondrian, the more flamboyant circular forms of Robert Delaunay working in Paris, the even more emotional fields of Wassily Kandinsky, the orgy of motion vectors of Italian futurists. The philosophical presuppositions and historical roots that led to the final emergence of "pure" abstraction in the 1910s are similarly multiple and diverse, coming from a variety of philosophical, political, and aesthetic positions: the ideas of synesthesia (the correspondence of sense impressions), symbolism, theosophy, communism (abstraction as the new visual language for the proletariat in Soviet Russia), and so on. And yet it is possible and appropriate to point to a single paradigm that both differentiates modernist abstraction from realist painting of the nineteenth century and simultaneously connects it to modern science. This paradigm is *reduction*.

In the context of art, the abstraction of Mondrian, Kandinsky, Delaney, Kupka, Malevich, Arp, and others represents the logical conclusion of a gradual development of the preceding decades. From Manet, impressionism, post-impressionism, symbolism to fauvism and cubism, the artists progressively streamline and abstract the images of visible reality until all recognizable traces of the world of appearances are taken out. This reduction of visual experience in modern art was a very gradual process that began in the early nineteenth century,[6] but in the beginning of the twentieth century we often see the whole development replayed from the beginning to the end within a single decade—such as in Mondrian's paintings of a tree from between 1908 and 1914. Mondrian starts with a detailed, realistic image of a tree. By the time he has finished his remarkable compression, only the essence, the idea, the law, the genotype of a tree is left.[7]

This visual reduction that took place in modern art between approximately 1860 and 1920 perfectly parallels the dominant scientific paradigm of the nineteenth and early twentieth centuries.[8] Physics, chemistry, experimental psychology, and other sciences were engaged in the deconstruction of the inanimate, biological, and psychological realms into simple, further indivisible elements, governed by simple and universal laws. Chemistry and physics postulated the levels of molecules and atoms; later on, physics broke atoms down further into elemental particles. Biology saw the emergence of the concepts of cell and chromosome. Experimental psychology applied the same reductive logic to the human mind by postulating the existence of further indivisible sensorial elements, the combination of which would account for perceptual and mental experience. For instance, in 1896 E. B. Titchener (former student of Wundt, who brought experimental psychology to the U.S.) proposed that there are 32,800 visual sensations and 11,600 auditory sensory elements, each just slightly distinct from the rest. Titchener summarized his research program as follows: "Give me my elements, and let me bring them together under the psychophysical conditions of mentality at large, and I will guarantee to show you the adult mind, as a *structure*, with no omissions and no superfluity."[9]

It can be easily seen that the gradual move toward pure abstraction in art during the same period follows exactly the same logic. Similarly to physicists, chemists, biologists, and psychologists, the visual artists have focused on the most basic pictorial elements—pure colors, straight lines, and simple geometric shapes. For instance, Kandinsky in *Point and Line to Plane* advocated a "microscopic" analysis of three basic elements of form (point, line, and plane) claiming that there are reliable emotional responses to simple visual configurations.[10] Equally telling of Kandinsky's program are the titles of the articles he published in 1919: "Small Articles about Big Questions. I. About Point," and "II. About Line."[11]

While the simultaneous deconstruction of visual art into its most basic elements and their simple combinations by a variety of artists in a number of countries during the first two decades of the twentieth century echoes the similar developments in contemporary science, in some cases the connection was much more direct. Some of the key artists who were involved in the birth of abstraction were closely following the research into the elements of visual experience conducted by experimental psychologists. As experimental psychologists split visual experience into separate aspects (color, form, depth, motion) and subjected these aspects to a systematic investigation, their articles begin to feature simple forms such as squares, circles, and straight lines of different orientations, often in primary colors. Many of the abstract paintings of Mondrian, Klee, Kandinsky, and others look remarkably similar to the visual stimuli already widely used by psychologists in the previous decades. Since we have documentation that at least in some cases the artists were following the psychological research, it is not unlikely that they directly copied (consciously or unconsciously) the shapes and compositions of the psychology literature. Thus abstraction was in fact born in psychological laboratories before it ever reached the gallery walls.

Complexity

The reductionist method appears to rule the science of the twentieth and early twenty-first centuries and artistic evolution in the same period. But while

Malevich, Mondrian, and others were pushing reduction in art to its logical conclusion during the 1910s and 1920s, different paradigms which are not based on reduction already appeared in the sciences during this time. Freudian psychology is no longer trying to understand the mind in terms of interaction between simple elements. Similarly, instead of simple laws that govern the world in Newtonian physics, quantum mechanics deals with probabilities and accepts the Heisenberg uncertainty principle. Other examples of non-reductionist thinking in sciences in the decades that follow include work by John von Neumann on cellular automata in the late 1940s and 1950s, and the work of Lewis Fry Richardson on what is now known as fractals in the same period.

Beginning in the 1960s, scientists in fields other than physics gradually realize that the classical scientific approach, which aims to explain the world through simple universally applicable rules (such as the three laws of Newtonian physics), cannot account for a variety of physical and biological phenomena. Toward the end of this decade, artificial intelligence research which was trying to reduce the human mind to symbols and rules, also ran into difficulties. At this time, a new paradigm begins to emerge across a number of scientific and technical fields, eventually reaching popular culture as well. It includes a number of distinct areas, approaches, and subjects: chaos theory, complex systems, self-organization, autopoiesis, emergence, artificial life, neural networks, the use of models, and metaphors borrowed from evolutionary biology (genetic algorithms, "memes"). While distinct from each other, most of these fields share certain basic assumptions. They all look at complex dynamic and nonlinear systems and they model the development and/or behavior of these systems as the interaction of a collection of simple elements. This interaction typically leads to emergent properties—*a priori* unpredictable global behavior. In other words, the order that can be observed in such systems emerges spontaneously; it cannot be deduced from the properties of elements that make up the system. Here are the same ideas expressed in somewhat different terms: "orderly ensemble properties can and do arise in the absence of blueprints, plans, or discrete organizers; interesting wholes can arise simply from interacting parts; enumeration of parts cannot account for wholes; change does not necessarily indicate the existence of an outside agent or force; interesting wholes can arise from chaos or randomness."[12]

According to the scientists working on complexity, the new paradigm is as important as the classical physics of Newton, Laplace, and Descartes, with their assumption of a "clockwork universe." But the significance of the new approach is not limited to its potential to describe and explain the phenomena of the natural world that were ignored by classical science. Just as classical physics and mathematics fitted perfectly the notion of a highly rational and orderly universe controlled by God, the sciences of complexity seem to be appropriate in a world that on all levels—political, social, economic, technical—appears to us to be more interconnected, more dynamic, and more complex than ever before. So, in the end, it does not matter if frequent invocations of the ideas of complexity in relation to just about any contemporary phenomenon—from financial markets to social movements—are appropriate or not.[13] What is important is that having realized the limits of linear top-down models and reductionism, we are prepared to embrace a very different approach, one that looks at complexity not as a nuisance which needs to be quickly reduced to simple elements and rules, but instead as the source of life—something that is essential for the healthy existence and evolution of natural, biological, and social systems.

Let us now return to the subject this essay is about—contemporary software abstraction and its role in a global information society. I am now finally ready to name the larger paradigm I see behind the visual diversity of this practice—from stylish animations and backgrounds that populate commercial websites to the online and offline works that are explicitly presented by their creators as art. This paradigm is complexity. If modernist art followed modern science in reducing the media of art—as well as our sensorial experiences and ontological and epistemological models of reality—to basic elements and simple structures, contemporary software abstraction instead recognizes the essential complexity of the world. It is therefore not accidental that time-based software artworks often develop in a way that is directly opposite to the reduction that took place over the years in Mondrian's paintings—from a detailed figurative image of a tree to a composition consisting of just a few abstract elements. Today we are more likely to encounter the opposite: animated or interactive works that begin with an empty screen or a few minimal elements that quickly evolve into a complex and constantly changing image. And while the style of these works is often fairly minimal—vector graphics and pixel patterns rather than an orgy of abstract expressionism (see my "Generation Flash" for a discussion of this visual minimalism as a new modernism[14])—the images formed by these lines are typically the opposite of the geometric essentialism of Mondrian, Malevich, and other pioneers of modern abstraction.

The patterns of lines suggest an inherent complexity to the world that is not reducible to some geometric phenotype. The lines curve and form unexpected arabesques rather than traversing the screen in strict horizontals and verticals. The screen as a whole becomes a constantly changing field rather than a static composition.

When I discussed modernist abstraction, I pointed out that its relationship to modern science was twofold. In general, the reductionist trajectory of modern art that eventually led to a pure geometric abstraction in the 1910s parallels the reductionist approach of contemporary sciences. At the same time, some of the artists actually followed the reductionist research in experimental psychology, adopting the simple visual stimuli used by psychologists in their experiments for their paintings.

Since designers and artists who pursue software abstraction are our contemporaries and we share the same knowledge and references, it is easy for us to see the strategy of direct borrowing at work. Indeed, many designers and artists use the actual algorithms from scientific publications on chaos, artificial life, cellular automata, and related subjects. Similarly, the iconography of their works often closely followed the images and animations created by scientists. And some people manage to operate simultaneously in the scientific and cultural universes, using the same algorithms and same images in their scientific publications and art exhibitions. One example is Karl Sims who, in the early 1990s, created impressive animations based on artificial life research that was shown at Centre Pompidou in Paris which he also described in a number of technical papers. What is less obvious is that in addition to the extensive cases of direct borrowing, the aesthetics of complexity is also present in the works that do not directly use any models from complexity research. In short, just as was the case with modernist abstraction, the abstraction of the information era is connected to contemporary scientific research both directly and indirectly—through a direct transfer of ideas and techniques, and indirectly as part of the same historically specific imagination.

Here are some examples, all drawn from an online section of the Abstraction Now exhibition. This unique exhibition presented in Vienna in 2003 included an approximately equal number of software-driven and more "traditional" abstraction works.[15] Thus it created an environment for thinking about software-driven abstraction within the larger context of modern and contemporary art. I decided to test my hypothesis by systematically visiting every online work in the exhibition in the order in which they were presented

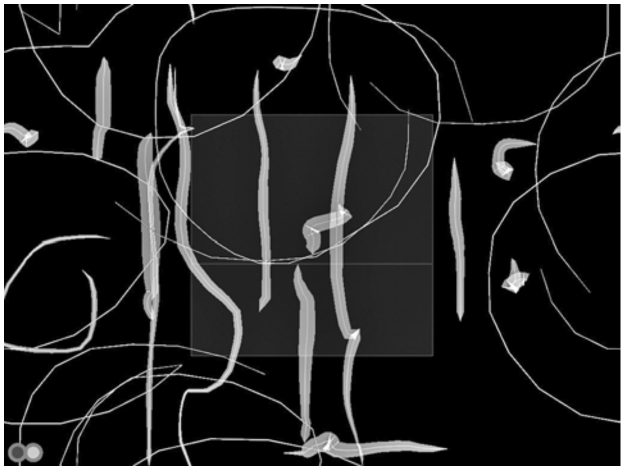

Figure 16.1 Golan Levin, *Yellowtail*, 2002. See plate 12.

on the website, rather than selecting only a few works that would fit my preconceived ideas. I have also looked at all the accompanying statements—none of which as far I can see explicitly evokes the sciences of complexity. My experiment worked even better than I expected since almost all pieces in the online component of the show follow the aesthetics of complexity, invoking complex systems in the natural world more often and more literally than I had anticipated.

Golan Levin's *Yellowtail* software amplifies the gestures of the user, producing ever-changing, organic-looking lines of constantly varying thickness and transparency (see fig. 16.1). The complexity of the lines and their dynamic behavior make the animation look like a real-time snapshot of some biologically possible universe. The work perfectly illustrates how the same element (i.e., a line) that in modernist abstraction represented the abstract structure of the world now evokes instead the world's richness and complexity. (Similar effects are at work in the piece by Manny Tan.) In other words, if modernist abstraction assumes that behind the sensorial richness of the world there are simple abstract structures that generate this richness, such a separation of levels is absent from software abstractions. Instead, we see a dynamic interaction of elements that periodically leads to certain orderly configurations.

Insertsilence by James Paterson and Amit Pitaru starts with the few tiny lines moving inside a large circle; a click by the user immediately increases the complexity of the already animated line cob, making the lines multiply, break, mutate, and oscillate until they "cool down" to form a complex pattern which sometimes contains figurative references. While the artists' statement makes no allusion to the complexity sciences, the animation in fact is a perfect illustration of the concept of emergent properties.

As I have already noted, software artworks often deploy vector graphics to create distinctly biological-looking patterns. However, a much more modernist-looking rectangular composition made from monochrome color blocks can also be reworked to function as an analogue to the complex systems studied by scientists. The pieces by Peter Luining, Return, and James Tindall evoke typical compositions created by students at Bauhaus and Vhkutemas (the Russian equivalent of Bauhaus). But again, with a single click by the user the compositions immediately come to life, turning into dynamic systems whose behavior no longer evokes the ideas of order and simplicity. As in many other software pieces that subscribe to the aesthetics of complexity, the behavior of the system is neither linear nor random—instead it seems to change from state to state, oscillating between order and chaos—again, exactly like the complex systems found in natural world.

While some of the software pieces in the Abstraction Now exhibition adopt the combinatorial aesthetics common to both early modernist abstraction and 1960s minimalism (in particular, the works by Sol LeWitt), this similarity only makes more apparent a very different logic at work today. For instance, instead of systematically displaying all possible variations of a small vocabulary of elements, *Arp* code by Julian Saunderson from Soda Creative Ltd. constantly shifts the composition without ever arriving at any stable configuration (fig. 16.2). The animation suggests that the modernist concept of "good form" no longer applies. Instead of right and wrong forms (think for instance of the war between Mondrian and Theo van Doesburg), we are in the presence of a dynamic process of organization that continuously generates different forms, all equally valid.

If the works described so far were able to reference complexity mainly through the dynamic behavior of rather minimal line patterns, the next group of works uses algorithmic processes to generate dense and intricate fields which often cover the whole screen. Works by Glen Murphy, Casey Reas, Dexto, Meta, and Ed Burton (also from Soda) all fit into this category. But just as with the works described so far, these fields are never static, symmetrical, or simple—instead they constantly mutate, shift, and evolve.

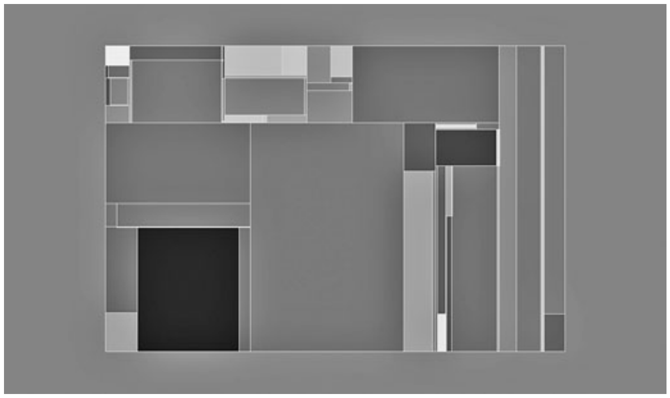

Figure 16.2 Julian Saunderson, *Arp*, 1990.

I could go on multiplying examples but the pattern should be quite clear by now. The aesthetics of complexity which dominates the online works selected for the Abstraction Now show is not unique to them; a quick scan through works regularly included in other exhibitions such as (whitneybiennial.com, curated by Miltos Manetas), Ars Electronica, or Flash Forward demonstrates that this aesthetics is as central for contemporary software abstraction as reductionism was for early modernist abstraction.

I have chosen this particular exhibition for my analysis because the software works it presented can be thought of as the direct equivalent of modernist abstract practice. They are neither functional nor do they claim to represent anything external to them. However, other explicitly functional areas of contemporary digital art and design—such as information visualization or Flash interfaces—often use the same visual strategies. So while my examples come from the area of "pure abstraction," the paradigm of graphical complexity also operates in the realm of design. This is similar to the way in which modernist visual abstraction was developed and employed. The abstract impulse was simultaneously pushed further and further in the nineteenth and early twentieth centuries in both art and design. And when pure abstraction was achieved in the 1910s and early 1920s, different artistic movements such as suprematism and De Stijl immediately applied it across many areas—from paintings and graphics to two-dimensional and three-dimensional design and architecture.

The space limitations of this essay do not allow me to go into the important question of what is happening today in abstract painting (which is a very

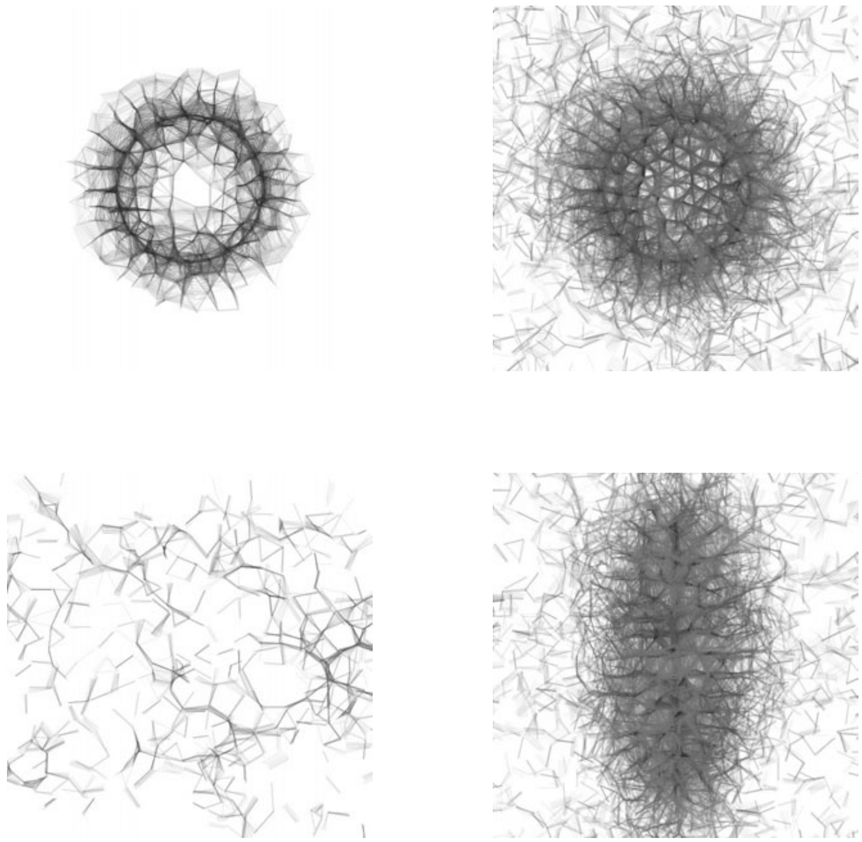

Figure 16.3 Casey Reas, *Articulate*, 2003. See plate 13.

active scene in itself) and how its developments connect (or not) to the developments in software art and design as well as to contemporary scientific paradigms. Instead, let me conclude by returning to the question I posed in the beginning: what sorts of representations are adequate for the needs of a global information society, characterized by new levels of complexity (in this case understood in descriptive rather than in theoretical terms)? As I have suggested, practically all of the developments in computer imaging so far can be understood as responses to this need. But this still leaves open the question of how to represent the new social complexity symbolically. While software abstraction usually makes more direct references to the physical and biological than the social, it may also be appropriate to think of many works in this paradigm

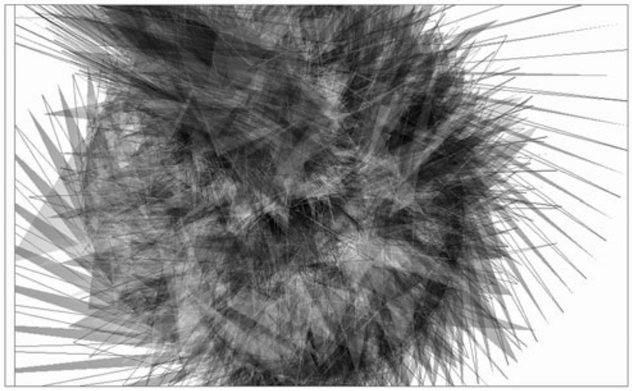

Figure 16.4 Meta, *Graf*, 2002.

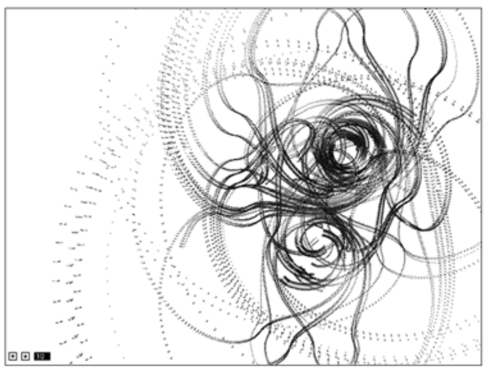

Figure 16.5 Lia, *Withouttitle*, 2003.

as such symbolic representations. For they seem to quite accurately and at the same time poetically capture our new image of the world—as the dynamic networks of relations, oscillating between order and disorder—always vulnerable, ready to change with a single click of the user.

Notes

1. I rely here on the influential analysis of Manuel Castells who characterizes the new economy that emerged at the end of the twentieth century as informational, gobal and networked. See Manuel Castells, *The Rise of the Network Society*, vol. 1: *The Information Age*, 2nd ed. (Malden, Mass.: Blackwell, 2000), 77.

2. Lars Qvortrup, *Hypercomplex Society* (New York: Peter Lang Publishing, 2003).

3. I am grateful to Cristiane Paul who carefuly reviewed this essay and offered a number of valuable suggestions.

4. The notion of computer as metamedium was clearly artciculated by the person who, more than anybody else, was responsible for making it a reality by directing the development of GUI at Xeroc Parc in the 1970s—Alan Kay. See Alan Kay and Adele Golberg, "Personal Dynamic Media" (1997), in *The New Media Reader*, ed. Noah Wardrip-Fruin and Nick Monfort (Cambridge, Mass.: MIT Press, 2003), 394.

5. In *The Language of New Media* I describe this effect in relation to the cinematic interface, i.e., the camera model, which in computer culture has become a general interface to any data that can be represented in 3-D virtual space. But this is just a particular case of a more general phenomenon: the simulation of any media in software allows for the "virtualization" of its interface. Lev Manovich, *The Language of New Media* (Cambridge, Mass: MIT Press, 2001.)

6. Consider, for instance, the exhibition "The Origins of Abstraction," Musee d'Orsay, Paris, November 5, 2003, to February 23, 2004. See Norbert Pfaffenbichler and Sandro Droschl, eds., *Abstraction Now* (Vienna: Camera Austria, 2004).

7. I am again grateful to Christiane Paul, who pointed out to me that the reduction applies to modernist abstraction before World War II. From the 1940s, we see a different aesthetics at work as well, which Paul characterizes as "expansive" and "excessive" (de Kooning, Pollock, Matta, and others).

8. For a detailed reading of modern art as the history of a reduction that parallels the reductionism of modern science and in particular experimental psychology, see the little-known but remakable book *Modern Art and Modern Science*. This section is based on the ideas and the evidence presented in this book. Paul Vitz and Arnold Glimcher, *Modern Art and Modern Science: The Parallel Analysis of Vision* (New York: Praeger Publishers, 1984).

9. Quoted in Eliot Hearst, "One Hundred Years: Themes and Perspectives," in *The First Century of Experimental Psychology*, ed. Eliot Hearst (Hillsdale, N.J.: Erlbaum), 25.

10. Wassily Kandinsky, *Point and Line to Plane* (1926) (New York: Solomon R. Guggenheim Foundation, 1947).

11. Yu. A. Molok, "'Slovar simvolov' Pavla Florenskogo. Nekotorye margonalii." (Pavel Florensky's "dictionary of symbols." A few margins). *Sovetskoe Iskusstvoznanie* 26 (1990), 328.

12. See http://serendip.brynmawr.edu/complexity/complexity.html/.

13. For examples of works that apply the ideas of complexity to a range of fields, see Manuel de Landa, *A Thousand Years of Nonlinear History* (New York: Zone Books, 1997); Howard Rheingold, *Smart Mobs: The Next Social Revolution* (Cambridge, Mass.: Perseus Publishing, 2002); Steven Johnson, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (New York: Scribner, 2001).

14. Available at http://www.manovich.net/.

15. Abstraction Now, curated by Norbert Pfaffenbichler and Sandro Droschl, Kunstlerhaus, Vienna, 2003.