The Mapping of Space:

PERSPECTIVE, RADAR, AND 3D COMPUTER GRAPHICS

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1991 saw two events, of different importance and seemingly unrelated. One was the long-awaited publication in English of what can probably be called the single most influential essay of modern art history—Erwin Panofsky's Die Perspektive als 'Symbolische Form.'[1] The interest generated around the re-emergence of this legendary essay, written in 1924-1925,[2] demonstrates that the problem of perspectival representation is still felt to be relevant to contemporary culture. The second event was the Gulf War, the outcome of which was largely predetermined by Western superiority in the techniques of perspectival representation.

The images, extensively televised during the Gulf War, perfectly confirmed Paul Virilio's thesis that modern warfare became a matter of the "logistics of perception."[3] True, broadcasts have included more traditional views of soldiers, planes, and tanks as seen from the outside by a video camera of a reporter. But what we also saw were not just images of the war, but endless images of the means by which the war was carried out: video images from an infrared camera mounted on a plane; video images from a camera installed on a weapon guided by a laser sensor; video in its role as "battle damage assessment" where a weapon equipped with an imaging device follows a weapon of destruction and records details of the damage. This was no longer a traditional report's view of a battle. We saw what the soldiers themselves saw: the images that were their only information about the enemy. More often, in a strange case of identification we witnessed what was "seen" by a machine, a bomb, or a missile.

The Gulf War was the combat of surveillance against camouflage, visibility against invisibility, human eye against computer eye. This warfare was indeed based on the "logistics of perception" but we can describe its visual techniques even more precisely. Visual perception was employed in a limited way as an instrument to capture and represent information about shapes and distances in 3D space. The effectiveness of such war technologies as radar, infrared imaging, laser sensors, and 3D computer graphics depends on the automation of this function of vision, the automation that began with the Renaissance perspective.

The use of these technologies today extends beyond warfare into all spheres of industry and science. Is there an appropriate term to describe the function of vision that they automate? For Plato, sensible particulars were but a pure reflection of ideas or forms. Aristotle criticized Plato, declaring that the primary substances were not the ideas but the individual things such as particular man or animals. These opposing views continued to be debated in scholastic philosophy, Plato's view giving rise to realism, and Aristotle's—to nominalism.

This essay will discuss 20th century automation of what can be called visual nominalism—the use of vision to capture the identity of individual objects and spaces by recording distances and shapes. The automation of this function of vision has started well before the century with the development of various perspectival techniques and technologies: perspective machines (such as the camera Lucida) descriptive and perspective geometry, and photography. But only digital computers made possible mass automation in general, including the automation of visual nominalism.

"The Most Important Event of the Renaissance"

According to a widely accepted narrative, perspective was already dead by the time art historians such as Panofsky began writing its history. Such narrative is announced, for instance, in the very title of Pierre Francastel's (Painting and Society; Birth and Destruction of Plastic Space from Renaissance to Cubism) (1952). The opening section of The Production of Space by Henri Lefebvre is equally authoritative:

> The fact is that around 1910, a certain space was shattered. It was a space of common sense, of knowledge (savoir), of social practice, or political power . . . a space, too, of classical perspective and geometry, developed from the Renaissance onward on the basis of the Greek tradition (Euclid, logic) and bodied forth in Western art and philosophy, as in the form of the city and town.[4]

Yet, if perspective disappeared from modern art, it survived as one of the techniques of visual nominalism, a method for precisely representing a 3D world on a 2D surface. In this role, it extended into new domains (the whole of the electromagnetic spectrum) and became the foundation of new kinds of automated remote sensory technologies.

To consider perspective in this role we should turn to William Ivins' influential 1939 essay, "On the Rationalization of Sight." Ivins's approach stands in sharp contrast to the more traditional art historical analyses of perspective by Panofsky and Francastel. They are concerned with perspective as artistic form and do not look beyond its history in art. Ivins, on the contrary, is concerned with visual culture—the techniques and technologies of visual representation available to a society at a given moment and the fundamental role they play in shaping every aspect of society. Ivins argued that perspective allows the creation of precise maps of 3D reality, to record the shapes of concrete objects and the layout of concrete spaces.[5] It is the tool of a businessperson and a scientist rather than an artist. In Ivins's definition, perspective is "a practical means for securing a rigorous two-way, or reciprocal, metrical relationship between

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the shapes of objects as definitely located in space and their representations."[6]

Thus Ivins singles out the precise relationship established between objects and their representations as the most important principle of perspective. Bruno Latour recently extended this idea by pointing out that this relationship, made possible by perspective, allows us not only to represent reality but also to control it.[7] Latour sees perspectival representations as the "most powerful instrument of power," defined as the ability to mobilize resources across space and time and to manipulate these resources at a distance. For instance, we can't measure the sun in space directly, but we only need a small ruler to measure it on a photograph (perspectival image par excellence). And even if we could fly around the sun, we would still be better off studying the sun through its representations that we can bring back from the trip—because now we have unlimited time to measure, analyze, and catalog them. We can also move objects from one place to another by simply moving their representations: "You can see a church in Rome, and carry it with you in London in such a way as to reconstruct it in London, or you can go back to Rome and amend the picture." Finally, as Latour points out, "the two ways become a four-lane freeway! Impossible palaces can be drawn realistically, but it is also possible to draw possible objects as if they were utopian ones." Real and imagined objects can meet on a flat space of perspectival representation.

Ivins concludes his essay by stating that the beginning of the rationalization of sight through the discovery and the development of perspective "was the most important event of the Renaissance." The invention of perspective-propelled modern empirical science, for instance biology, which could now represent forms of nature with mathematical precision. It also stimulated the rise of modern engineering and manufacturing by making feasible the distribution of identical designs to far away places.

Modern designers, scientists, or engineers, of course, do not simply use perspective in the form in which it was formulated by Alberti in the 15th century; they have at their disposal much more sophisticated techniques. According to Ivins, the rationalization of perspectival sight proceeded in two directions. On the one hand, perspective became the foundation for the development of the techniques of descriptive and perspective geometry, which became a standard visual language of modern engineers and architects. On the other hand, the photographic technologies automated the creation of perspectival images. Both were the accomplishments of the 19th century; in fact, both were developed more or less simultaneously. Indeed, as Ivins points out, Nièpce and Talbot, the founders of photography, were contemporaries of Monge and Poncelet, the decisive figures in the development of descriptive and perspective geometry.

Radar: Seeing without Eyes

Writing On Rationalization of Sight between 1936 and 1938, Ivins mentions such examples of the contemporary use of perspective as aerial photographic surveillance, classification in the field of archeology, and criminal detection.[8] However, all these applications of perspectival techniques already existed in the 19th century and, by the 1930s, did not represent the latest developments.

While photo reconnaissance was first employed systematically on a mass scale during World War I, the interest in using photography for aerial surveillance existed since its invention. Nadar succeeded in exposing a photographic plate at 262 feet over Bièvre, France in 1858. He was soon approached by the French Army to attempt photo reconnaissance but rejected the offer. In 1882, unmanned photo balloons were already in the air; a little later, they were joined by photo rockets both in France and in Germany. The only innovation of World War I was to combine aerial cameras with a superior flying platform—the airplane.[9]

In 1858, Albrecht Meydenbauer, a director of the Government Building Office, published a proposal to use photographs for scale measurement. His proposal was based on the existence of a geometrical relationship between photographic image and the object being photographed. Why, for instance, climb a facade of a cathedral in order to measure it (as Meydenbauer had to do, nearly getting killed once) when it is much safer to measure a photograph? Additionally, wrote Meydenbauer, "some may find it hard to believe, but experience has proven that one can see, not everything, but many things, better in scale measurement than on the spot." In 1885 the Royal Prussian Institute for Scale Measurement was founded and the measurement of photographs of historic monuments became a frequent practice.[10]

It is possible that in the 20th century the "rationalization of sight" was not responsible for any new applications? In fact, while Ivins was writing his essay on perspective, across the Atlantic, in England, work was already underway to install twenty radar stations on the east and southeast coasts to provide surveillance of these air approaches.[11] These radar installations turned out to be absolutely essential in the coming war, allowing for the severely outnumbered Royal Air Force to defeat Luftwaffe in the Battle of Britain. Radar, the latest technology of visual nominalism, became Britain's most important weapon.[12]

Radar is an acronym for Radio Detection and Ranging. Like sound waves, radio waves create echoes when they are reflected by objects in their path. Radar transmits a radio wave in a desired direction. The signal reflected back from the objects is picked up by radar antenna. The time between the transmission and the reception of the echo indicates the distance to the object; the direction the antenna is pointing in when the echo is received reveals the object's position in relation to the radar. Detected objects appear as bright spots on the display watched by a radar operator.[13]

Radar is the best example of the rationalization of sight in the 20th century. All it sees and all it shows are the positions of objects, 3D coordinates of points in space, points that correspond to submarines, aircraft, birds, or missiles. Color, texture, even shape are disregarded. Instead of Alberti's window, opening onto the full richness of the visible world, a radar operator sees a screen, a dark field with a few bright spots. Here, the function of visual nominalism, which perspectival image performed along with many other functions, is isolated and abstracted.

Radar image serves a single function—but it performs it more efficiently than any previous perspectival technique or technology.

First, vision is no longer limited by the spectral capacity of the human or camera eye. Instead of relying, like photography, on the small region of the electromagnetic spectrum to which our eyes are sensitive, radar uses other regions, sending and receiving waves of different lengths. Vision is extended to include other sections of the electromagnetic spectrum. The visible becomes a small part of a larger field of sensory exploration of the environment. Consequently, the recording of objects' positions in space is no longer limited by conditions of visibility.

Second, this recording now takes place in real time. No longer do military commanders have to wait until pilots come back from surveillance missions and the film is developed. Now, the imaging is instantaneous. The image changes in real time, reflecting the change in the referent.

Along with radar, many other technologies of visual nominalism came into existence following the advances in electronics and computers during World

War II: ultrasonic imaging, multi-spectral photography, multi-spectral imaging, infrared, sonar, magnetic-resonance imaging, and so on. As radar, these technologies are effectively used to record distances, positions, layouts, shapes, and volumes. Sonar, for instance, detects objects in the water by using sound waves. Ultrasonic computer tomography uses sound waves and computer graphics to construct images of body tissues. Multi-spectral photography isolates energy reflected from surfaces in a number of given wavelength bands.

Engineering textbooks and encyclopedias group these technologies under the term "remote sensing," defined as the gathering and imaging of information without actual contact with the object or area being investigated.[14] This definition is helpful in separating the two operations involved in the technologies of remote sensing: the gathering of information and its presentation. The first operation may have nothing to do with what is visible to the human eye but in the second operation the eye eventually comes into play since the gathered information has to be presented to the human observer in visual form in order to be useful.

However, these technologies do not only perform the role previously played by perspectival representations but also rely on the same principle. Nobody is more clear on this point than Jacque Lacan. In "Of the Gaze as Object Petit a" from The Four Fundamental Concepts of Psycho-Analysis, Lacan emphasizes that perspective extends beyond the domain of the visible.[15]

Lacan starts by reminding us that an image is anything defined "by a point-by-point correspondence of two unities in space." To obtain an image of something we do not have to rely on light or to operate in the domain of the visible. Nor do we have to limit images to 2D representations of 3D reality. We can represent an object by another object or represent a 2D form by another form. All that is required is a rule to establish the correspondence between the points of the object being imaged and the points on the image.

Similarly, says Lacan, "what is an issue in geometric perspective is simply the mapping of space, not sight."[16] Perspective is one such rule, a particular method to establish a correspondence between the object and its image. Specifically, the method of perspective consists in connecting a single point in space (usually referred to as the point of view) with a number of points on the object by straight lines; the intersection of these lines with a plane creates an image. The fact that perspective, whether as a part of human sight apparatus or as a part of an apparatus of photography, works through light is coincidental. Light travels in straight lines; therefore it can be used to create perspectival images. But one can construct such images without light: "In Descartes, dioptrics, the action of the eyes, is represented as the conjugated action of two sticks."[17] As Lacan points out further on in the seminar, this idea that perspective is not limited to sight alone but functions in other senses as well defines the classical discourses on perception: "The whole trick, the key presto!, of the classic dialectic around perception derives from the fact that it deals with geometric vision, that is to say, with vision in so far as it situated in a space that is not in its essence the visual."[18]

Lacan's clarification that the principle of perspective is not limited to the visible helps us understand that the technologies of remote sensing function on the principle of perspective. Regardless of their lengths, all waves travel in straight lines, and therefore points in space are connected by straight lines to a point of reception (such as radar antenna) or recording (such as photographic camera). Radar, infrared imaging, sonar, or ultrasound are all part of what Lacan called "geometric vision," perspectival vision that extends beyond the visible.

3D Computer Graphics: Interactive Perspectivalism

From the moment of adaptation of perspective attempts have been made to aid the laborious manual process of creating perspectival images.[19] Between the 16th and the 19th centuries, various perspectival machines (more precisely, perspective aid devices) have been invented. They have been used to construct particularly challenging perspectival images, to illustrate the principles of perspective, to help students learn it, to impress artist's clients or to serve as intellectual toys. Already in the first decades of the 16th century, Dürer described a number of such machines.[20] One device is a net in the form of a rectangular grid, stretched between the artist and the subject. Another uses a string representing a line of sight. The string is fixed on one end, while another end is moved successively to key points on the subject. The point where the string crosses the projection plane, defined by a wooden frame, are recorded by two crosses strings. For each position, a hinged board attached to the frame is moved and the point of intersection is marked on its surface. Other major types of perspectival machines that appeared subsequently included perspectograph, pantograph, physionotrace, and optigraph.

Why manually move the string imitating the ray of light from point to point? Along with perspectival machines a whole range of optical apparatuses was in use, particularly for depicting landscapes and in topographic surveys. They included the versions of camera obscura from large tents to smaller, easily transportable boxes. After 1800, artist's ammunition were strengthened by camera lucida, patented in 1806.[21] Camera lucida utilized a prism with two reflecting surfaces at 135 degrees. The draftsman carefully positioned his eye to see both the image and the drawing surface below and traced the outline of the image with a pencil.

The images produced by camera obscura or camera lucida were only ephemeral and considerable effort was still required to fix these images. A draftsman had to meticulously trace the image to transform it into the permanent form of a drawing.

With photography this time-consuming process was finally eliminated. The process of imaging reality, the creation of perspectival representations of real objects, was now mechanized. However, this mechanization did not affect other uses of perspectival representation. According to Latour, perspective establishes a "four-lane freeway" between reality and its representation. We can combine real and imagined objects in a single geometric model and to go back and forth between reality and the model. The process of the creation of a geometric model still remained a manual process, requiring techniques of perspectival and analytical geometry, pencil, rule, and eraser. Similarly, to construct a perspectival view of the model also required hours of drafting. The mechanization and automation of geometrical modeling and display was yet to come.

Nothing perhaps symbolizes mechanization as dramatically as the first assembly lines installed by Henry Ford in 1913. The assembly line relied on two crucial principles. The first principle was the standardization of parts, already employed in production of military uniforms in the 19th century. The second, newer principle, was the separation of production process into a set of repetitive, sequential and simple activities that could be executed by workers who did not have to master the entire process and could be easily replaced.

It seemed that mechanical modernity was at its peak. Yet, in the same year, the Spanish inventor Leonardo Torres y Quevedo already advocated the industrial use of programmed machines.[22] He pointed out that although automatons existed before, they were never used to perform useful work:

> The ancient automatons . . . imitate the appearance and movement of living beings, but this has not much practical interest, and what is wanted is a class of apparatus that leaves out the mere visible gestures of man and attempts to accomplish the results that a living person obtains, thus replacing a man by a machine.[23]

With mechanization, the work is performed by a human but the physical labor is augmented by a machine. Automation takes mechanization one step further—a machine is programmed to replace the functions of human organs of observation, effort and decision.

The term "automation" was finally coined in 1947, and in 1949 Ford began the construction of its first automated factories. Automation was made possible by the development of digital computers during World War II and thus became synonymous with computerization. A decade later, the automation of the process of constructing perspectival images of both existent and non-existent objects and scenes was well underway.[24] By the early 1960s Boeing designers already relied on 3D computer graphics for simulation of landings on the runway and of pilot movement in the cockpit.[25]

By automating perspectival imaging digital computers completed the process begun in the renaissance. The automation became possible because perspectival drawing has always been a step-by-step procedure, an algorithm involving a series of steps required to project coordinates of points in 3-D space onto a plane. Before computers, the steps of the algorithm were executed by human draftspersons and artists. The use of a computer allowed to execute them automatically and, therefore, much more efficiently.[26]

The details of the actual perspective-generating algorithm that could be executed by a computer were published in the early 1960s by Larry G. Roberts, then a graduate student at MIT.[27] The perspective-generating algorithm constructs perspectival images in a manner quite similar to traditional perspectival techniques. In fact, Roberts had to refer to German textbooks on perspectival geometry from the early 1800s to get the mathematics of perspective.[28] The algorithm reduced reality to solid objects, and the objects are further reduced to planes defined by straight lines. The coordinates of the endpoint of each line are stored in a computer. Also stored are the parameters of a virtual camera—the coordinates of a point of view, the direction of sight and the position of a projection plane. Given this information, the algorithm generates a perspectival image of an object, point by point.

Computerization of perspectival construction made possible the automatic generation of a perspectival image of a model as seen from an arbitrary point of view—a picture of a virtual world recorded by a virtual camera. The picture, however, was crude and static. To produce a film of a simulated landing, Boeing had to supplement computer technology with manual labor. As in traditional animation, 24 plots were required for each second of film. These plots were computer-generated and consisted of simple lines. Each plot was then hand-colored by an artist. Finished plots were filmed, again manually, on an animation stand.

Gradually, throughout the 1970s and the 1980s, the coloring stage was automated as well. Many algorithms were developed to add the full set of depth cues to a synthetic image—hidden line and hidden surface removal, shading, texture, atmospheric perspective, shadows, reflections, and so on.[29]

In 1962, Ivan Sutherland designed his legendary Sketchpad program. With Sketchpad, a human operator could create graphics directly on a computer screen by touching the screen with a light pen. In the same year, ITEK began marketing Electronic Drafting Machine similar to Sketchpad.[30] Although both programs only dealt with 2D graphics, they introduced a new paradigm of interactive graphics: by changing something on the screen, the operator changed data in computer memory.[31]

When this paradigm of interactive editing was combined with the algorithms of 3D graphics, a fundamentally new way to use perspectival images emerged. This development was more revolutionary than automation of perspective construction per se. Indeed, a traditional draftsperson could have accomplished what the computer at Boeing was doing—generating plots in perspective given by a 3D database—only more slowly. But now it became possible to change the point of view of a virtual camera and see the corresponding changes in the perspectival image in real time. It also became possible to interactively build and modify 3D models and observe the changes on the screen.

The emergence of interactive 3D computer graphics started the race to eliminate the time delay between the action of an operator and the displayed results. In this race for speed, which accelerated in the 1970s as synthetic images began to be utilized in flight simulators, the algorithms of 3D graphics were gradually transported from software into hardware, each algorithm becoming a special computer chip. Silicon Graphics, one of the major manufactures of computer graphics hardware, labeled such a system a "geometry engine."

The term appropriately symbolizes the second stage of the automation of perspectival imaging. At the first stage, a photographic camera, with perspective physically built into its lens, mechanized the process of creating perspectival images of existing objects. Now, with perspectival algorithm and other necessary geometric operations embedded in silicon, it is possible to display and interactively manipulate models of non-existent objects as well.

Conclusion

In this century, automation of visual nominalism has entered a new stage. The signs of this automation are a multitude of new technologies used to capture and visualize 3D reality that merged since the middle of the 20th century such as radar, infrared imaging, laser sensors, CAT scan, magnetic resonance imaging, 3D computer graphics, and computer holography. Since the early 1960s, work has also been under way to automate vision completely, to create computer vision systems that would recognize objects and interpret scenes automatically.

The development of these technologies has been accompanied by massive research into the general problems of visual nominalism in computer science, experimental psychology, and neuroscience. New formal mathematical techniques were developed to analyze an image as a source of depth information and, vice versa, to transform this information into realistic images. The work on automation of visual nominalism has also lead to the new attention to particular aspects of human vision. In fact, a new paradigm for the study of human vision has emerged during 1970s at MIT. Within this paradigm, the goal of human vision is taken to be the recognition of shapes, leading researchers to study algorithms by which the brain "computes" shapes of objects from retinal input in the hope that these algorithms can be then used by computer vision systems.[32] The emergence of such a paradigm, which reduces human vision to a particular function, and the accompanying research investment suggest the economic importance of this function of vision for the contemporary society.

Notes

1. Erwin Panofsky, Perspective as Symbolic Form, New York: Zone Books, 1991.
2. Erwin Panofsky, "Die Perspektive als 'Symbolische Form'," Vörtage der Bibliothek Warburg, (Leipzig and Berlin: 1927), 258-330.
3. Paul Virilio, War and Cinema: the Logistics of Perception, (London: Verso, 1989).
4. Henri Lefebvre, The Production of Space, (Oxford: Blackwell Publishers, 1991), 25.
5. William Ivins, On the Rationalization of Sight, (New York: Da Capo Press, 1975).
6. Ibid., 9.
7. Bruno Latour, "Visualization and Cognition: Thinking with Eyes and Hands," Knowledge and Society: Studies in the Sociology of Culture Past and Present 6 (1986): 1-40.
8. Ivins, 12-13.
9. Beaumont Newhall, Airborne Camera, (New York: Hastings House, Publishers, 1969). For critical histories of photo reconnaissance see Allan Sekula, "The Instrumental Image: Steichen at War," Photography against the Grain: Essays and Photo Works, 1973-1983, (Halifax: The Press of the Nova Scotia College of Art and Design, 1984); Paul Virilio, War and Cinema: the Logistics of Perception, (London: Verso, 1989); Manuel De Landa, "Policing the Spectrum," War in the Age of Intelligent Machines, (New York: Zone Books, 1991).
10. Harun Farocki, "Reality Would Have to Begin," Documents 1/2 (1992): 136-146.
11. This section relies on two sources: Echoes of War, (Boston: WGBH Boston), videotape; McGraw-Hill Encyclopedia of Science and Technology: an International Reference Work in Twenty Volumes Including Index, (New York: McGraw-Hill, 1992).
12. Principles and technology of radar were worked out independently by scientists in the U.S., England, France, and Germany during the 1930s. After the beginning of the War, only the U.S. had the necessary resources to continue radar development. In 1940, at MIT, a team of scientists was gathered to work in the Radiation Laboratory or the "Rad Lab," as it came to be called. The purpose of the lab was radar research and production. The lab's first achievement was the successful competition of microwave radar that was small enough to fit on a plane.
13. Numerous variations of the basic radar technology exist. For instance, in addition to active radars that send a signal and detect energy reflected by the objects, there are also passive radars that do not send a signal themselves. However, all radars have in common the use of electromagnetic radiation (radio waves) to detect and measure objects in their vicinity.
14. McGraw-Hill Encyclopedia of Science and Technology: an International Reference Work in Twenty Volumes Including Index, (New York: McGraw-Hill, 1992), vol. 15, 311.
15. Jacques Lacan, "On the Gaze as Object Petit a," The Four Fundamental Concepts of Psycho-Analysis, Ed. Jacques-Alain Miller, Trans. Alan Sheridan, (New York: W.W. Norton & Company, 1981), 67-122.
16. Ibid., 86.
17. Ibid, 87.
18. Ibid., 94.
19. For a survey of perspectival instruments, see Martin Kemp, The Science of Art, (New Haven: Yale University Press, 1990), 167-220.
20. Ibid., 171-172
21. Ibid., 200.
22. Charles Eames and Ray Eames, A Computer Perspective: Background to the Computer Age, (Cambridge, MA: Harvard University Press, 1990), 65-67.
23. Qtd. in ibid., 67.
24. I am not aiming here by any means to provide a full account of the history of 3D computer graphics or its various uses. I am concerned with computer graphics as one development, among others, in the general move toward the rationalization of perspectival imaging. For a more comprehensive account of 3D computer graphics techniques, see J. William Mitchell, The Reconfigured Eye: Visual Truth in the Post-Photographic Era, (Cambridge, Massachusetts: The MIT Press, 1992), 117-162.
25. Jasa Reichardt, The Computer in Art, (London and New York: Studio Vista and Van Nostrand Reinhold Company, 1971), 15.
26. MIT became the major early research site for yet another new technology of visual nominalism—computer graphics. The Radiation Laboratory was dismantled after the end of the War, but soon the U.S. Air Force created another secret laboratory in its place—Lincoln Laboratory. The job of Lincoln Laboratory was to work on human factors and new display technologies for SAGE—the "Semi-Automatic Ground Environment," a command center to control the U.S. air defenses established in the mid-1950s. As part of this research, conducted through the 1950s and the 1960s, Lincoln Laboratory developed many key principles and technologies of computer graphics—CRT (cathode-ray tube) display, bit-mapped graphics, interactive control and algorithms for 3D wire frame graphics. See Paul Edwards, "The Closed World. Systems discourse, military policy and post-World War II U.S. historical consciousness," Cyborg Worlds: The Military Information Society, Ed. Les Levidow and Kevin Robins (London: Free Association Books, 1989); Howard Rheingold, Virtual Reality, (New York: 1991).
27. L.G. Roberts, "Machine Perception of Three-Dimensional Solids," MIT Lincoln Laboratory TR 315, 1963; L.G. Roberts, "Homogeneous Matrix Representations and Manipulation of N-Dimensional Constructs," MIT Lincoln Laboratory MS 1405, 1965.
28. "Retrospectives II: The Early Years in Computer Graphics at MIT, Lincoln Lab, and Harvard," SIGGRAPH '89 Panel Proceedings, (Boston, Massachusetts: ACM SIGGRAPH, 1989), 72.
29. For further discussion of the problem of realism in computer graphics, see Lev Manovich, "'Real' Wars: Aesthetics and Professionalism in Computer Animation." Design Issues 6, no. 1 (Fall 1991): 18-25; Lev Manovich, "Assembling Reality: myths of Computer Graphics," Afterimage 20, No. 2 (September 1992): 12-14.
30. "Retrospectives II: The Early Years in Computer Graphics at MIT, Lincoln Lab, and Harvard," SIGGRAPH '89 Panel Proceedings, (Boston, Massachusetts: ACM SIGGRAPH, 1989), 51.
31. In fact, interactive computer graphics technology appeared earlier, although it was not publicized. Already in the 1950s, the Air Force used interactive CRT displays and light pens in order to process more efficiently the information obtained by radar. Both CRT displays and light pens were designed at Lincoln Laboratory as part of the SAGE project. Using this technology, Lincoln researchers created a number of computer graphics programs. They include programs that allowed to display brain waves (1957), to simulate planet and gravitational activity (1960), and to create 2-D drawings (1958). "Retrospectives II: The Early Years in Computer Graphics at MIT, Lincoln Lab, and Harvard," SIGGRAPH '89 Panel Proceedings, (Boston, Massachusetts: ACM SIGGRAPH, 1989), 42-54.
32. The fundamental statement of this paradigm, David Marr's Vision defines human vision as "the process of discovering from images what is present in the world, and where it is." David Marr, Vision, (New York: W. H. Freeman and Company, 1982), 3.

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