Shifting Perspectives

Holography and the Emergence of Technical Communities

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In November 1964, a bemused magazine journalist recorded this scene in a crowded Boston hotel suite:

> A few dozen normally sedate scientists and engineers were playing with a toy locomotive, a toy train-conductor and other such items. The train wasn't really there at all. But if you stood in exactly the right place and looked into a piece of equipment you would have seen it, real as life. The toys had been "reconstructed" by a technique that looks simple, yet is one of the most sophisticated developments in modern science. The "reconstruction" was done with a gas laser made by Perkin-Elmer Corp., and a "hologram," a special photographic plate made by researchers at the University of Michigan.[1]

The hotel gathering mirrored the surprise of optical specialists at a remarkable paper given at a conference in Washington, D.C., eight months earlier. As the paper's coauthor, Emmett Leith, recalled of that first demonstration: "There was a big exodus of people from the meeting room. . . . We went up and found a line that stretched down the hall as far as you could see. They would look at the hologram, and even though most of them were optical scientists, they did not understand what was going on. They assumed it was

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1. George V. Novotny, "The Little Train that Wasn't," *Electronics* 37 (30 November 1964): 86–89, quotation on 86.

a projection system done with mirrors, and that the little toy train was hidden somewhere."[2]

The members of the expert audiences at these 1964 meetings struggled to fit this stunning new type of image into their understanding of optics. Their varying success in doing so illustrated a gradual process of intellectual adaptation and cultural mutation. This extraordinary new technology, sprouting in a quiet disciplinary backwater, was taken up by existing technical communities and gave rise to new ones. Technology and technical communities grew together, mutually shaping and stabilizing each other.

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During its first fifty years, the itinerant subject latterly known as holography was repeatedly reconceptualized in new intellectual and geographical territories. Conceived in 1947 by Dennis Gabor, an émigré Hungarian research engineer at British Thomson-Houston in England, as a means of improving image quality in electron microscopy, it was variously dubbed "holoscopy," "wave front reconstruction," and "diffraction microscopy," as a handful of researchers pursued it over the ensuing decade.[3] As an "improved" form of microscopy it was eventually judged to have severe limitations: electron microscopes proved too unstable to yield the necessarily long photographic exposures, and the optical technique itself was marred by an undesired "conjugate" image. By 1958 research had ceased, and the sole industrial laboratory pursuing the technique had categorized it as a white elephant.[4] Holography was revitalized unexpectedly in the early 1960s by electrical engineers and physicists combining findings in information theory and coherent optics with newly available lasers.[5]

The novel principle behind the invention of holography is a two-step imaging process. First, an interference pattern (the "hologram") is recorded by superposing two beams of light, one reflected from the subject and the other traveling directly from the light source. The light must have a high degree of coherence, that is, a well-defined wavelength and stability of phase. Since 1963, holograms have almost exclusively been recorded using lasers, but other light sources, such as filtered mercury lamps, have adequate coherence for some purposes. The interference pattern of the holo-

2. Jeff Hecht, "Applications Pioneer Interview: Emmett Leith," *Lasers and Applications* 5 (April 1986): 56–58, quotation on 56.

3. The most important of some fifty publications on the subject before 1960 are Dennis Gabor, "A New Microscopic Principle," *Nature* 161 (1948): 777–78, and "Microscopy by Reconstructed Wavefronts," *Proceedings of the Royal Society of London*, ser. a, 197 (1949): 454–87; Hussein M. A. El-Sum, "Reconstructed Wave-Front Microscopy" (Ph.D. diss., Stanford University, 1952).

4. T. E. Allibone, "White and Black Elephants at Aldermaston," *Journal of Electronics and Control* 4 (1958): 179–92. The Associated Electrical Industries (AEI) research lab at Aldermaston, U.K., had researched the electron microscope portion of the "diffraction microscope," while Gabor and a student worked on the "optical reconstruction" portion.

5. The first continuous-wave visible-light lasers were produced in late 1961; "pulsed" lasers were developed for human portraits from 1967 on.

gram is recorded on a photosensitive material such as high-resolution photographic film. Because these materials are very insensitive to light and must record patterns finer than several thousand lines per millimeter, the long exposure normally restricts the technique to inanimate objects. Nevertheless, methods of synthesizing holograms from cinema film allow images of outdoor scenes and living subjects to be reconstructed in three dimensions and with limited animation.

The second step of the imaging process is the reconstruction of the wave front of light by illuminating the hologram with a suitable light source. Until the end of the 1960s, most holograms had to be viewed using lasers, but "reflection holograms" and "rainbow holograms" later liberated holography from this requirement.[6] The product of these technologies is an astonishingly lifelike image providing not only three-dimensional views but different perspectives ("parallax") as well.

Holography, with its realistic three-dimensional imagery and capabilities of exquisitely sensitive optical measurement, was taken up and successively recast by a burgeoning group of technical communities. Emerging from classified radar research at the University of Michigan, it revitalized the field of optical engineering and created a new specialty, the "holographer." It grew rapidly from 1965–72, supported by lavish military and industrial funding. Over the following decade holography became a cottage industry, and after the mid-1980s it established itself in several market niches, such as packaging, and security holograms on credit cards. Pioneering this growing commercial exploitation, however, were new communities, particularly artist-artisans, who made holography their own by developing it as an artistic medium. These "aesthetic holographers" contrasted with earlier workers in important ways, and constituted a distinct subculture.

This article argues that holography is an unusual example of a technology that has spawned highly dissimilar and sometimes contending practitioner groups and consequently can serve as a sensitive probe of the mutual interactions that shape technologies and community identities. The techniques, understandings, and purposes of holography were successively reworked between roughly 1955 to 1975 by loosely affiliated groups of proponents, ranging from military scientists and hybridized engineers to

6. Reflection holograms were devised by Yury Denisyuk of the Vavilov State Optical Institute in Leningrad between 1958 and 1961, rediscovered experimentally by several groups in the United States in late 1965, and further developed during the 1970s. Rainbow holograms, originated by Stephen Benton of Polaroid in 1968, were developed in the United States from the early 1970s and proved popular with artists. A third variant, the "image plane hologram," invented in 1966 and viewable in filtered light, produces shallow three-dimensional images near, or indeed passing through, the hologram surface. For all varieties, illumination remained a serious technical constraint, requiring a point source of light shining on the hologram at a precise angle.

artists and enthusiasts exploring countercultural interpretations. In the process, the technology and the user communities coevolved to support a growing differentiation of equipment, practices, and products. While such interaction and divergence is a common feature of new technologies, holography provides an extreme case.[7]

The coevolution of these communities reveals a very unusual shifting of authority across the scientific-artistic divide. In some respects—links with science, military funding, and technological progressivism—holography's trajectory looks like that of other commonplace late-twentieth-century technologies. But its ties to aesthetic and countercultural trends influenced its direction in distinctive ways. The expansion and, in some domains, contraction of holography and the specialist groups that grew up around it illustrate the competing scientific, commercial, and aesthetic visions at play in the development of modern technologies. The following discussion will, therefore, focus on the practitioners, their tools, and their intellectual and cultural products, exploring how holography's varied technical communities became differentiated in occupational, disciplinary, professional, and philosophical respects via the technology itself.

For narrative clarity, the article concentrates on two geographical areas: the University of Michigan and the San Francisco Bay Area of California. While holography rapidly became an international field, its subcultures were defined and established by the exploratory activities in these locales during the early 1960s and early 1970s, respectively.

Historical accounts of holography have, to date, been written almost wholly by practitioners, and perhaps as a consequence have been subjective and limited in scope.[8] The research presented here, part of a wider study of the history of holography, is based on oral histories and written correspondence conducted with some eighty individuals, as well as on published sources and archival collections at Imperial College, London; the MIT Museum, Cambridge, Massachusetts; the Bentley Historical Library, Ann Arbor, Michigan; and the private collections of individual holographers.[9]

7. Many technologies foster new communities—computer users' groups, for example. Holography, however, generated an unusually broad spectrum of technical communities divided by tools, products, and philosophies.

8. For analysis of early accounts of holography, see Sean F. Johnston, "Telling Tales: George Stroke and the Historiography of Holography," *History and Technology* 20 (2004): 29–51. The divergence and social instability of the technical communities around holography exacerbated the inconsistency of these accounts.

9. Imperial College, London, holds the papers of Dennis Gabor, who was awarded the Nobel Prize in 1971 for his work on holography, and those of Gordon Rogers. The MIT Museum, Cambridge, stores the publications and records of the New York Museum of Holography (MoH) (1976–92), described by its last director as "the keeper of the culture"; Martha Tomko, "What's Going On at the MoH?" letter to the editor, *holosphere* 17 (spring 1990): 4–5. For a bibliographic survey of publications on holography, see Sean F. Johnston, "Reconstructing the History of Holography," *Proceedings of SPIE—The*

Taken collectively, these sources allow the construction of a balanced and insightful perspective.

The definition of a holographer was first articulated in the mid-1960s as a specialty within optical engineering. That field was itself in flux at the time, as demands increased for rapid-exposure still and cinema cameras to record events such as nuclear explosions and tracking equipment to film such fast-moving objects as missiles. Optical engineers of the period combined skills in traditional geometrical optics with expertise in mechanical integration.[10] The original name of the professional organization for American optical engineers, the Society of Photographic Instrumentation Engineers (SPIE), founded in 1955 with an initial membership of seventy-four, reflected the field's orientation toward camera design.[11] Nevertheless, by the early 1960s optical engineering had become a disciplinary nexus for tension between traditional optics and electrical engineering. It had also begun a process of transformation, the crucial geographical location of which was the University of Michigan's Willow Run Laboratories (WRL).

The labs had been established at the Willow Run Airport, near Ann Arbor, Michigan, as a center for classified research after World War II, when the university's Department of Electrical Engineering attracted contracts for guided missile research (Project Wizard). By the early 1950s the Willow Run Laboratories were the site of a wide range of investigations in infrared, radar, acoustics, and computing focused on battlefield surveillance (Projects Wolverine and Michigan). The ruby maser, a unique invention that straddled the worlds of electrical engineering and optics, was invented there in 1957. A more direct confrontation of disciplinary perspectives grew up at the Radar and Optics Laboratory, established in 1953 as part of the Willow Run Laboratories, which was tasked with developing methods to analyze the data from synthetic aperture radar (SAR). Emmett Leith, a recent physics graduate from nearby Wayne State University and a junior engineer, began investigations into optical methods of signal processing. Beginning in the mid-1950s, he conceived a connection between SAR processing and optical interference patterns.[12]

International Society of Optical Engineering 5005, *Practical Holography XVII and Holographic Materials IX*, ed. Tung H. Jeong and Sylvia H. Stevenson (2003), 455–64.

10. By "traditional optics" I mean the dominant form of optics practiced in the United States until the 1950s, which is sometimes also referred to as "classical optics." This concerns the design of optical elements and systems and largely ignores the subtle complicating effects of diffraction, interference, and coherence, which have been crucial to the development of holography and the wider field that is known as "modern optics."

11. Owing to the importance of Department of Defense (DoD) funding for optical engineering, the SPIE was also militarily and nationally oriented. In 1964, for example, one-third of the local SPIE chapters were located on military testing ranges or bases (including China Lake, California; Vandenberg Air Force Base, California; Kwajalein launch facility, Marshall Islands; and White Sands, New Mexico).

12. Emmett N. Leith, "A Data Processing System Viewed as an Optical Model of a

After successful testing in 1958, the WRL optical processor for SAR data became the accepted tool among the radar community, which was dominated by electrical engineers. The power and potential of the new technique of "optical information processing" were classified; when the synthetic aperture radar was publicly announced, its optical processing was kept quiet.[13]

After 1960, with his research assistant Juris Upatnieks, Leith began applying insights about optical processing to explore its connections with Dennis Gabor's wave-front reconstruction, which had been abandoned by previous workers as impracticable. Leith and Upatnieks applied communications theory to physical optics, yielding a powerful new way of understanding the concept and redressing its limitations. They generated high-quality holograms first with a mercury lamp and, from 1963, with the newly available laser (fig. 1). Their invention, popularly dubbed "lensless photography," crossed the no-man's-land between classified research and public awareness.

When Leith and Upatnieks announced three-dimensional holograms publicly, the sixteen engineers of the Radar and Optics Lab enthusiastically launched a variety of research studies, supported by funding from the Department of Defense. Willow Run became the model for a new, expanded version of optical engineering. These engineers picked up a practical understanding of optics in the half-dozen well-equipped optical labs at WRL; several went on to complete advanced degrees working on holography, and thereafter to careers as private-sector research and development engineers and entrepreneurs. The new field thus promoted a migration across the boundaries that separated classified research from open academic studies and industrial exploitation.

Radar System," memo to W. A. Blikken of Willow Run Laboratories, University of Michigan, Ann Arbor, 22 May 1956, Leith collection. To date, the best historical accounts of these events are those provided by Leith and Yury Denisyuk of the Vavilov Institute, the principal historical actors, in Emmett N. Leith, "The Origin and Development of the Carrier Frequency and Achromatic Concepts in Holography" (Ph.D. diss., Wayne State University, Detroit, 1978); Emmett N. Leith, "A Short History of the Optics Group of the Willow Run Laboratories," in *Trends in Optics*, ed. A. Consortini (New York, 1996), 1–26, and "The Evolution of Information Optics," *IEEE Journal of Selected Topics in Quantum Electronics* 6 (2000): 1297–304; Yu. N. Denisyuk, "The Work of the State Optical Institute on Holography," *Soviet Journal of Optical Technology* 34 (1967): 706–10; Yu. N. Denisyuk and V. Gurikov, "Advancement of Holography, Investigations by Soviet Scientists," *History and Technology* 8 (1992): 127–32. The third person linking radar engineering with optics was Adolf Lohmann in Germany; see A. W. Lohmann, "Optical Single Side Band Transmission Applied to the Gabor Microscope," *Optica Acta* 3 (1956): 97–99.

13. See, for example, Philip Dodd, "A Spy in the Sky! Army Unveils Radar Camera: It Shoots Enemy Thru Clouds of Smoke," *Chicago Daily Tribune*, 20 April 1960. Leith recalls: "It wasn't the optical computing but it was the optical computing and synthetic aperture radar, that was the secret. You could talk about one or the other, but not both in the same breath." Emmett N. Leith, interview by author, 11 September 2003, Ann Arbor.

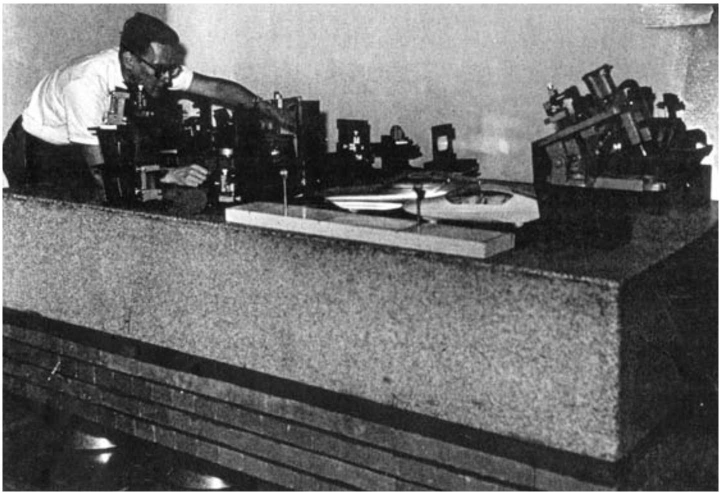

FIG. 1 Representing a scientific-technical community: the holographer Juris Upatnieks at a granite optical table in the Radar and Optics Lab of Willow Run Laboratory, 1965. (University of Michigan News Service photo, from the private collection of Emmett Leith.)

This first community of holographers based the cognitive foundations of their subject on the hybridization of two fields. At the time, optical processing and holography fit awkwardly into existing disciplines. Electrical engineering, in which signal processing was becoming a routine tool, seemed to share few intellectual principles or practical skills with optics. Disciplinary vocabularies jarred: at Willow Run, the concepts of electronic engineers and optical physicists were increasingly combined, as "decibels" became interchangeable with "optical transmission losses." University administrators, recognizing the challenges presented by this merging of disciplines, sought to teach "electro-optics" in the electrical engineering department and moved the Radar and Optics Group to the university campus. Administrators saw no incongruity in positioning "modern optics" in the Department of Electrical Engineering. Indeed, the first professor of electro-optics at the University of Michigan, George W. Stroke, celebrated this intellectual melding and promoted electro-optical engineering as a crucial emerging discipline:

> Many of the most dramatic advances in the field of optics in the last decade or two were directly stimulated or originated by advances in electrical engineering, in its various branches of communication sciences, microwave electronics and radio-astronomy. . . . [T]he newly dramatic achievements in "lensless" photography and "automatic" character recognition, and nonlinear optics, are some of the more

> well known examples of the interdependence of theory and techniques. . . . Skilful recognition and exploitation of basic similarities in pursuits throughout the entire electromagnetic domain is proving most useful in pinpointing new areas of research and of industrial applications in what may be called "electro-optical science and engineering."[14]

Few academic institutions recognized anything approaching a discipline of electro-optics.[15] The same was true of journals. The first papers on holography necessarily were submitted to the journals that seemed either closest to the authors' professional allegiances (such as the organs of societies in which they were members) or most apt for the particular information to be communicated. In the process, the new subject stretched disciplinary boundaries.[16]

Optical engineering, a young specialty that adapted rapidly in a changing economic and political environment, seemed to offer the most suitable home for holography. With this new technology, optical engineers had expanded their cognitive domain, adding to both their theoretical toolbox

14. George W. Stroke, "An Introduction to Optics of Coherent and Non-Coherent Electromagnetic Radiations," course notes, May 1964, Bentley Historical Library, University of Michigan, Ann Arbor. Stroke had worked as an optical manufacturing manager in the late 1940s and as a research engineer on diffraction grating ruling engines at MIT during the 1950s, and completed a Ph.D. in optics at the Université de Paris in 1960. See also Johnston, "Telling Tales" (n. 8 above).

15. As late as 1978 the borders remained contentious. Nicholas George of the University of Rochester, New York, observed that his was the only American institution that awarded a bachelor's degree in the even broader category of optics. He denoted its graduates as "opto-electronic engineers," in contrast to the "electro-optical engineers" or "optical engineers" (as he characterized them) produced by Caltech, the University of Arizona, and a few other institutions. George commented that these were "a new breed of engineer, reflecting the close coupling of electronics and optics," and whose numbers had increased fivefold since the early 1950s; George to Rosemary Jackson, Museum of Holography, 42/1278, MoH Collection, MIT Museum. Similarly, John Gates in Britain saw optics itself as being in the throes of re-creation; J. W. C. Gates, "Holography, Industry and the Rebirth of Optics," *Review of Physics in Technology* 2 (1971): 173–91.

16. The set of journals changed as holography was redefined as a specialty. The early publications, exploring Gabor's concept of holography as a specialized technique for microscopy or the novelty of its imaging, appeared in journals of general science or physics such as *Nature*, *Zhurnal Tekhnicheskoi Fiziki*, *Journal of Applied Physics*, and *Oyo Buturi*. During the holography boom of the late 1960s, publications appeared as frequently in these as in a wide range of journals of modern optics (examples include *Optica Acta*, *Journal of the Optical Society of America*, *Optika i Spektroskopiya*, *Optics Communications*, *Optik*) and electronics (*Bell Systems Journal*, *Radiotechnika i Elektronika*, *Proceedings of the IEEE*). By the early 1970s, however, optical engineering, considerably boosted and valorized by increased military funding, was taking over the role that had been played by these publications. The American journals *Optical Engineering* and *Applied Optics* and the Russian journal *Optiko Mekhanicheskaya Promyshlennost* became important vehicles for papers on holography.

and their profession's status. Optical engineering's cognitive transition from traditional optics to modern optics occurred largely because its primary sponsor, the Department of Defense, had wholeheartedly adopted the sophisticated technologies of holography promoted by researchers such as Leith at Willow Run.

But a successful technical community usually requires more: it relies on an occupational focus, that is, recognizable and stable jobs based on acquired skills; an underlying intellectual basis, which may evolve into a discipline; and, if more widely recognized by contemporaries, a profession to consolidate social status. The occupation, at least, and the term "holographer" were established by 1966, a mere two years after three-dimensional holography had first been demonstrated. This identity was promoted not only by reliable military funding but also by the first dedicated conferences on the subject, which took place with growing frequency after 1967, especially under the auspices of the SPIE with the sponsorship of the Department of Defense and the National Aeronautics and Space Administration. The Gordon Research Conferences on Information Processing and Holography, held in association with the American Association for the Advancement of Science after 1972, were a further explicit attempt to strengthen social networks. These self-consciously defined the professional community of scientific holographers because the chair traditionally chose the speakers and invited participants. Thus, journals, secure funding, and dedicated conferences helped optical engineers to become a visible specialist group beginning in the mid-1960s. The key organizational step was the appropriation by optical engineers of the intellectual perspectives and potential dividends of holographic technology. In return, the engineers' working context defined the scope and content of the technology. This complementary coevolution gave stability to both the field of optical engineering and those working in it.

The nascent community of holographers was centered on a small but growing number of sites. Initially, industrial laboratories highly dependent on military contracts (such as TRW Defense and Space Systems, Lockheed, Hughes Aircraft, Aerodyne Research, Rockwell, Grumman Aerospace, and Harris Electronic Division) pursued holographic applications under Defense Department contracts, while other large industrial laboratories (among them Bell Telephone, Radio Corporation of America, Texas Instruments, the Columbia Broadcasting System, and McDonnell Douglas) explored commercial applications such as optical data storage, communications, and imaging. Most of these sites, though well funded, were largely invisible to the wider culture; holographers were isolated from public interaction, even as they were becoming an increasingly self-aware community.

Optical engineering began to broaden its intellectual scope during the 1960s and 1970s, though it remained an important outlet for militarily funded research, especially in the developing field of digital image processing. *Optical Engineering* succeeded the *Journal of the SPIE* in 1972, and during the 1980s the SPIE became known by its acronym and the descriptor "The International Society for Optical Engineering," thereby consolidating an expanded identity for the new profession and de-emphasizing its narrow intellectual origins. The career profiles of SPIE members were shaped by their employment, and many continued to work in defense-related research.[17]

Thus, the working environment and special collection of practical skills defining the occupational identity of holographers were self-recognized by the late 1960s. At precisely that point definitions of the holographer began to diverge. The first sign of a new perspective on holography was the attraction of artists to this new medium, during a period when many were pursuing new connections between avant-garde art and technology.

In 1968, the artist Bruce Nauman approached the Conductron Corporation, which was then beginning to market its services in pulsed-laser holography for advertising, about collaborating on art holograms. Nauman eventually produced a number of holographic self-portraits, working with Conductron holographers. At about the same time, the painter Margaret Benyon, supported by a fellowship in the Department of Art History at the University of Nottingham, created her own holograms in a lab in the university's Department of Mechanical Engineering (fig. 2). Within a year the artists Karl Fredrik Reutersward in Stockholm and Harriet Casdin-Silver in Boston were also exploring the medium and exhibiting their works to small audiences. Itinerant explorers, such artists borrowed facilities and learned technique from scientists and engineers intrigued by the directions they pursued.[18] Working in conventional optical labs, these early aesthetic holographers absorbed the practices of the workers there.

17. The journal changed its name a few times over the course of a decade: from *SPIE Journal* (1962–63), to *Society of Photo-Optical Instrumentation Engineers Journal* (1964–69), to *Journal SPIE* (1970), to *Journal of the SPIE* (1971), and finally to *Optical Engineering*. Until the end of the cold war, entry into some SPIE meetings was restricted to American citizens or North American residents, slowing the dissemination of information deemed militarily sensitive. This connection between military interests and intellectual developments continues. The Strategic Defense Initiative (SDI, or "Star Wars," launched in 1983) was founded on the lasers, steerable lightweight mirrors, and optoelectronic receivers that dominated optical engineering developments, encouraging a dramatic increase in employment in the field. With the end of the cold war, the SPIE began to make good on its claim to be an international organization by opening chapters in the former Soviet Union. Through this disciplinary and geographical expansion, its membership grew from 1,000 in 1961 to 3,000 in 1980 and 14,000 in 1999. American defense technology remained an important focus, however. Following the events of 11 September 2001 and the Bush administration's establishment of a Department of Homeland Security, the SPIE formed a "Homeland Security Special Interest Group" in 2003.

18. Reutersward worked with scientists Nils Abramson and Hans Bjelkhagen at the Royal Institute of Technology in Stockholm. Benyon later made holograms at the University of Strathclyde, at the National Physical Laboratory near London, and at the

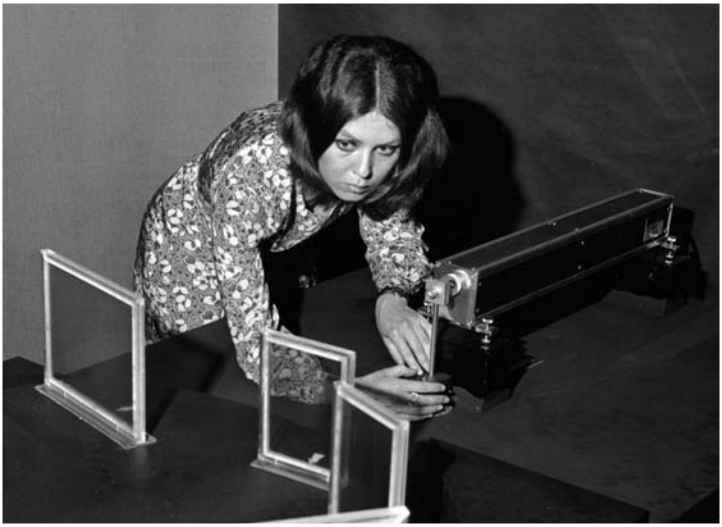

FIG. 2 Fostering a new constituency: the artist Margaret Benyon in 1970. (Central Office of Information, London, from the private collection of Margaret Benyon.)

The early aesthetic interpretations of holography changed its practitioners, its audiences, and its purpose. Until such collaborations, holograms had usually recorded mundane and readily recognized objects; Leith and Upatnieks, like most holographers, had recorded models of trains, tanks, and statues—objects sufficiently heavy and stable to remain motionless to within a fraction of a wavelength during exposures that could last from seconds to minutes. Artists, too, began with mimetic art, but new subjects sometimes required them to develop greater finesse. Exploring the possibilities of the new medium, artists began to branch into abstract variants and further nuances during the 1970s, literally sculpting with light.

The first holographic artists shared the facilities available in university labs, producing artwork that encouraged their scientist-engineer collaborators to consider technical extensions to holography in the areas of color, lighting, and subject. Artists pursued techniques and subjects scientists had considered unpromising or purposeless. Harriet Casdin-Silver, for example, rehabilitated a little-noticed technical innovation that Stephen Benton, a physicist at Polaroid, had pursued in 1968. Benton's "rainbow holography," which allowed a hologram to be viewed without a laser but was disparaged by colleagues for its lurid colors, was taken up enthusiastically by

Australian National University in Canberra. Casdin-Silver worked with Raoul Van Ligten at the American Optical Company, Stephen Benton of Polaroid, and Henrik Gerritsen at Brown University.

artists in the 1970s to overlay subtle hues and sophisticated effects in their holographic art pieces.[19]

Aesthetic holographers promoted public awareness of the medium with major exhibitions beginning in the 1970s.[20] Most orthodox holographers (that is, optical engineers and physicists) were unaware of these new practitioners until they encountered their revolutionary holograms in the neutral territory of public exhibitions.

Thus, a limited technological trade was pursued. The first generation of aesthetic holographers apprenticed alongside scientist-engineer counterparts, but valorized new techniques and new products that made holography more appealing and commercially viable. Nevertheless, the senior partner mediating this exchange was the conventional scientist-engineer, who was required, in effect, to translate the language and practice of orthodox holography for these undisciplined interlopers.[21] Indeed, artists felt this transgression of boundaries, too: Margaret Benyon recalls being asked by a member of the audience at an early public lecture she gave at the Royal College of Art in London, "how do you feel about using a laser that is an instrument of war?"[22]

There was, however, a significant shift in these power relations when aesthetic holographers adopted a perspective on the subject inspired by countercultural ideals. The wider youth culture drove this shifting definition, initially rejecting aspects of holography and then absorbing and mutating them. It is noteworthy that the University of Michigan was the birthplace of both laser holography and, in 1960, the Students for a Democratic Society.[23] While these two events had no initial correlation, their proximity

19. Even Benton, collaborating with Casdin-Silver on abstract holograms of laser diffraction patterns, decided that *Phalli*, a hologram of dildos intended as a feminist statement, went too far; Harriet Casdin-Silver, interview by author, 3 July 2003, Boston; Stephen A. Benton, interview by author, 11 July 2003, Cambridge, Mass.

20. Some five hundred shows, including large exhibitions in New York (1975, to largely critical reviews), Stockholm (1976), London (1977), Berlin, Rome, and Canberra (all in 1979), introduced holography to hundreds of thousands of people over the following two decades.

21. The metaphor of "trading zones" between workers in different fields, with communication occurring across these intellectual borders, has been powerfully developed for the case of experimental physics in Peter Galison, *Image and Logic: A Material Culture of Microphysics* (Chicago, 1997). The case of holography differs in that the communities under discussion share a single technology but are divided by their interpretations and goals, rather than being based upon distinctly different technologies applied to the same ends.

22. Benyon much later used the facilities at the Royal Military College at Duntroon, Canberra, to make antiwar holograms, but argued that the scientists and engineers giving her access to their facilities were, by such acts, acting as subversively as any artist; Margaret Benyon, interview by author, 21 January 2003, Santa Clara, Calif. In this unequal power relationship, it is significant that orthodox holographers were almost exclusively male, while aesthetic holographers showed a roughly equal gender balance.

23. For accounts of the youth movement, antiwar protests, and, especially, the role of students at Ann Arbor, see Irwin Unger and Debi Unger, *The Movement: A History of*

became significant within a decade. By 1965, student protests of the Vietnam War had begun to focus on institutions involved in classified research. The Radar and Optics Laboratory, relocated to the university's north campus, became a target; protesters staged a sit-in in 1967, and in October 1968 the laboratory was bombed. Centrally funded professional science and implicit notions of progress and materialism increasingly attracted student criticism. Military sponsorship of research at Willow Run became controversial enough that in 1973 the university decided to spin off the lab as an independent, not-for-profit research organization, the Environmental Research Institute of Michigan (ERIM).[24] Ann Arbor had become not only a major center for classified research and holography but also a cradle of political activism. Juris Upatnieks recalls: "Initially [at the U of M north campus], we could pursue any work we liked but during the Vietnam era, war protests began to hamper our choice of projects. Moving to ERIM removed this hindrance and we could proceed as before. Around 1970 . . . Congress prohibited the Defense Department from funding research that was not of direct interest to the military. Also, [the National Science Foundation] funded basic research only at educational institutions. These events limited what we could do at ERIM."[25]

Thus, the holographers at WRL/ERIM found the relatively unfettered research style of the early 1960s increasingly constrained by Congress on the one hand and student protests on the other. During the late 1960s, many consequently left to found or work at companies specializing in holography.[26] This conflict concerning the purpose and application of holographic research was an important factor encouraging the growth of distinct communities in specific locales.

The new aesthetic perspective on holography, and an artisanal community devoted to pursuing it, blossomed in the San Francisco Bay Area. A group of people came together there in the early 1970s that subverted some of the methods and values of orthodox holography while rejecting certain established social values as well.

A key figure in this transition was Lloyd G. Cross, who had gone to

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the American New Left, 1959–1972 (New York, 1974); Wini Breines, *Community and Organization in the New Left, 1962–1968: The Great Refusal* (New York, 1982); and John H. Bunzel, *New Force on the Left: Tom Hayden and the Campaign against Corporate America* (Stanford, Calif., 1983).

24. The same happened at Stanford University, another focus for holography research, in 1969, and at the MIT Research Laboratory in Electronics. See Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York, 1993).

25. Juris Upatnieks to author, electronic mail message, 15 May 2003.

26. The first wave of companies exploiting holography included Conductron Corporation, KMS Industries, GC-Optronics, Photo-Technical Research, Jodon Engineering, and the Optical Research Center of Radiation Inc., all based in Ann Arbor. The first two of these continued to generate income from military contracts.

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work at Willow Run Laboratories in the mid-1950s and while there contributed to the development of the ruby maser.[27] When Ted Maiman at Hughes Research Laboratories discovered laser action in this type of crystal in 1960, Cross, the project leader of a group installing a ruby maser preamplifier for a nearby radio telescope, organized after-hours development crewed by his maser project team. By early 1961 they had succeeded in constructing the third ruby laser and the first with a pulse powerful enough to pierce a razor blade, a demonstration that would become iconic in representations of the power of modern optics during the 1960s. Cross cofounded Trion Instruments in 1960 to develop the first commercial pulsed ruby lasers, and later joined KMS Industries as head of laser development to continue work on pulsed lasers suitable for holography. His first hologram—of a glass being filled from a champagne bottle, made to celebrate the project—used such a laser.

During the late 1960s, increasingly disenchanted with the funding and applications of laser research, Cross joined sculptor Jerry Pethick and artist/musician Peter Van Riper to explore laser light and holography in art, a scientist-artist collaboration with a difference. Pethick had studied art in Ontario and England, and returned to Canada curious about holography. During 1968, Pethick and Cross collaborated in setting up a basic holographic studio, first in Ann Arbor and then in London, England, spending "lots of time working together trying to simplify and justify what were then the formidable requirements of holography."[28] With Van Riper they formed a company called Editions in Ann Arbor that year, producing and selling art holograms during 1969–71. Cross started another firm in 1968, Sonovision, to pursue the use of laser-effects systems for entertainment purposes. Their holograms and laser shows were exhibited at their gallery and at the Finch College Museum of Art in nearby Detroit, and toured museums in upstate New York during 1970.

Through this period, Cross was making a transition between three communities: from the environment of militarily funded research at WRL, to commercial laser development, and finally to the domain of artist-scientist collaborations. After moving to San Francisco, Cross and Pethick played key roles in changing the practice of holography once more, to mesh with the expanding youth culture that had, to that point, been firmly antitechnological.

We can see a direct clash of perspectives in holographers' working environments and material culture, the equipment they used and the holo-

27. Cross was an undergraduate physicist at Willow Run in the lab of Chihiro Kikuchi, employed part time during 1956 as an assistant to research and from August 1958 in a full-time post.

28. Lloyd G. Cross and Cecil Cross, "HoloStories: Reminiscences and a Prognostication on Holography," *Leonardo* 25 (1992): 421–24, quotation on 422; Jerry Pethick, "On Sculpture and Laser Holography: A Statement," *Arts Canada* (1968): 70–71.

grams they produced. The Bay Area group became a technical community, but one very unlike that established at Willow Run. The key feature in the creation of this group was a new conception of the technology itself. In effect, Cross and Pethick reshaped the orthodox optical lab into an environment that was intellectually subversive and socially liberating.

Professional holographers had supported their self-definition by the apparatus they employed. The generous government and industrial sponsorship of the 1960s had allowed optical laboratory equipment to become increasingly sophisticated. For example, Michael Michalak, of the Goddard Space Flight Center, wrote of his beginnings in the field: "At first, we started making holograms on a laboratory bench using rather crude apparatus. New equipment and a granite slab soon put transmission holograms on a scientific rather than an artistic basis."[29]

Repeatable "scientific" results, he and his colleagues argued, required stability. Leith and Upatnieks had filled their train model with epoxy and glued it to a steel track to ensure adequate stability over the exposure time of several minutes. The arrangement of mirrors, object, and photographic plate had to remain motionless—within a margin of less than one wavelength of light—during the exposure to properly record the interference fringes making up the hologram. The solution was a heavy and rigid table on which to mount the apparatus. Leith correlated the increasing sophistication of holography with its increased requirements for stability, as "holography moved from its original place of performance on ordinary optical rails onto massive granite tables."[30]

However, a rigid mass also transmits high-frequency vibrations efficiently, which could perturb the lighter optical elements mounted on it. It was necessary, therefore, also to isolate this massive table from the environment. Some investigators, such as George Stroke, mounted their tables on solid foundations not attached to the walls of the building, an approach that had been adopted by researchers in astronomy and interference optics since the late-Victorian period.[31] Other labs employed more modern methods of vibration control, such as floating the heavy granite or marble slab on pistons operating in cylinders filled with compressed nitrogen.

Nor were mere weight and isolation from vibration enough. Smooth, solid surfaces were needed to position optical elements precisely. And a clean, dust-free environment was essential to produce diffraction patterns

29. Michael W. Michalak, "Holography in the Test and Evaluation Division at Goddard Space Flight Center" (paper presented at Holographic Instrumentation Applications Conference, NASA Ames Research Center, Moffett Field, Calif., 13–14 January 1970), 9–17.

30. Leith, "A Short History of the Optics Group" (n. 12 above), 23.

31. Frank Denton, telephone interview by author, 1 May 2003. This was true, for example, of Albert A. Michelson at the University of Chicago, who had developed interference spectroscopy and high-precision diffraction-grating ruling engines.

free of rings and blotches, as Dennis Gabor had found two decades earlier, battling against optical imperfections to achieve noise-free, or clean, images.[32] All these requirements called for a flat, massive, stable working surface and high-quality, spotless optical components. These became the de facto criteria for a serious holography laboratory, and the lack of such a table labeled a holographer as second rank.[33]

Such requirements were largely informal. Nor were many other practical necessities documented: how to mount, clean, and process plates; how to employ spatial filters effectively to remove imperfections of laser illumination; how to ensure bright hologram recordings. The tacit knowledge acquired by a generation of researchers defined the orthodox laboratory of coherent optics.

Lloyd Cross and Jerry Pethick challenged these conventions by developing a radically different set of skills and tools. Unlike his former colleagues at Willow Run and other professional laboratories, Cross had little money for equipment. He and Pethick initially planned to use a scaled-down table built of tombstone slabs.[34] Pethick conceived the idea of using sand as the required deadweight, filling a large plywood box with washed sand and mounting it on a semi-inflated inner tube to float the mass and isolate it from vibration (fig. 3). Optical components were then mounted on polyvinyl chloride (PVC) tubes sunk into the sand. Fine adjustments of angle and position were possible with this arrangement, and the sand kept the components in place and damped vibrations. If the apparatus was allowed to settle for a few minutes after being positioned, holographic exposures of several minutes were possible. Cross recalled: "We even applied for a patent, which for all I know may have been issued; but we decided not to attempt to keep the information a secret, which seemed a ludicrous thing to try to do with such a simple and basic concept. We quickly found out that even though the means were available to acquire and produce the technology, the art was still totally arcane to most people, except to those who were trained in it."[35]

From the start, then, the free flow of information was a guiding principle of their activities, in contrast to the restricted publication practices of classified and commercial research. So, too, was practicality and thrift. Cross later simplified the arrangement by replacing the plywood box with

32. The term "noise-free" applied to an optical image is a striking example of a carryover from communications theory. It has become synonymous with the term "clean," but was not used in this sense until the rise of coherent optics and optical engineers.

33. During the 1970s, lightweight but rigid honeycomb-structure tables manufactured by Newport Corporation became the standard for a professional holography lab.

34. Until the early 1970s, large, polished-granite slabs obtained from local tombstone suppliers and deadened by interleaving layers of balsa wood, brick, and rubber, were the surface of choice at the University of Michigan optical labs.

35. Cross and Cross (n. 28 above), 422.

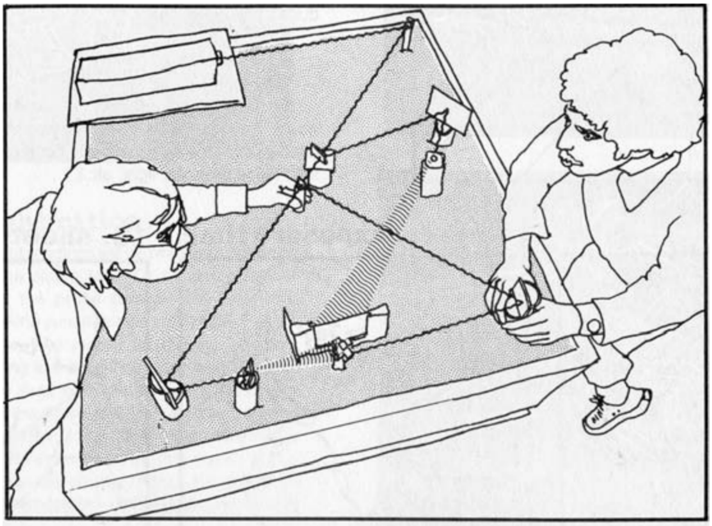

FIG. 3 Public-access holography: sandbox apparatus illustrated in Fred Unterseher, Jeannene Hansen, and Bob Schlesinger, *The Holography Handbook: Making Holograms the Easy Way* (Berkeley, Calif., 1982), 208. (Reproduced with permission of Ross Books, Berkeley, Calif.)

one made from heavy particleboard clamped in a tension structure. The particle board was inexpensive and, being a glued composite, was free of mechanical resonances, helping to damp vibrations further. It also made the entire table transportable: after removing the sand, unscrewing the boards, and deflating the inner tubes, the component parts could readily be moved and reassembled at the next rented basement or garage. Most important, it reduced the cost of a holography lab from some twenty thousand dollars to a few thousand.[36] The apparatus liberated its users from constraints of funding, location, and social stability. The technology was also intellectually subversive: no one—particularly a researcher in a well-funded lab—would previously have considered that abrasive sand and delicate optics could coexist in the same working environment.

Fabricating equipment from found materials symbolized a philosophy consciously embraced by Cross and his colleagues. During 1973–74, he devised a holographic camera for "multiplex," or integral, holography. The device, used for exposing strip holograms from individual frames of movie film, employed door springs as gears, cams made from particleboard, and large cylindrical lenses constructed from warped Plexiglas sheets sandwiching mineral oil (fig. 4). Reflecting on such ingenious improvisation,

36. "School of Holography Flourishes on West Coast," *holosphere* 2 (1973): 1, 5–6; "Bay Area Holography: An Historical View," *L.A.S.E.R. News* 2 (1985): 10–11.

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FIG. 4 Alternative technologies: Lloyd Cross, circa 1975, with cylindrical lens fabricated from Plexiglas and mineral oil. (Museum of Holography Collection, MIT Museum.)

Cross characterized his orientation as "not so much anti-technology as against the process and procedures of technical innovation which separate and isolate the technical specialties."[37]

The design philosophy had much in common with that espoused by the *Whole Earth Catalog*, the countercultural collection of tips, sources, and views that began publication in 1968 in Menlo Park, some 15 miles southeast of San Francisco and two miles from Stanford University.[38] The publishers described the purpose of the *Whole Earth Catalog* as supporting the development of "a realm of intimate, personal power—power of the individual to conduct his own education, find his own inspiration, shape his own environment, and share his adventure with whoever is interested." This individualistic, self-sufficient slant was allied with a mistrust of the large scale, because "so far remotely done power and glory—as via government, big business, formal education, church—has succeeded to the point where gross defects obscure actual gains."[39] This did not translate into a rejection of technology per se; indeed, the publishers of the *Whole Earth Catalog* cited the freethinking technologist Buckminster Fuller as their

37. Lloyd Cross to author, electronic mail message, 25 October 2003.

38. Interestingly, Stewart Brand, editor of the original *Whole Earth Catalog*, wrote a book two decades later lauding the high-tech future promised by MIT researchers, particularly the holography research of Stephen Benton. See Stewart Brand, *The Media Lab: Inventing the Future at MIT* (New York, 1987).

39. Stewart Brand, *Whole Earth Catalog: Access to Tools* (Menlo Park, Calif., 1970), inside front cover.

inspiration. The catalog was filled with an eclectic assortment of tools, book reviews, poetry, and observations on science, technology, philosophy, sociology, politics, and more. It expressed a growing amalgam of sentiments concerning individualism, alternative technologies, holistic perspectives, and opposition to authority.

Cross and Pethick attracted followers who proselytized for this vision. During a peripatetic three years, they had traveled both separately and together between Chicago, New York, and Arizona, finally settling in San Francisco, during which time their entourage had grown.[40] Their activities proved magnetic, and one source of this magnetism was the excitement of seeing well-produced, aesthetically pleasing holograms—still a rare experience for both scientists and the public. Cross and Pethick exhibited their holograms at the Exploratorium in San Francisco, a novel center where interactive exhibits had been designed, like their own holographic equipment, from low-cost, nonstandard materials. The exhibition attracted students to Cross and Pethick, and in 1971 the group looked for permanent premises. Scouring the Bay Area, they found that their special requirements for a quiet laboratory did not seem well suited to their demeanor. Fred Unterseher, one of the original members of the group, recalls: "They had to 'check the vibrations in your building'—and owners thought they were totally nuts. One guy said, 'You guys aren't going to make drugs, are you?' And, of course, we looked the part."[41] They moved to a cavernous warehouse in the Mission District that year. There the San Francisco School of Holography trained hundreds of practitioners, many of whom became active in art and commercial holography. The basic sixteen-hour course, costing $67.50, attracted an assortment of students, from "biker guys, to little old ladies, housewives and stuff; a Marin County lady rubbing shoulders with a hippy, and a biker kid."[42]

Jerry Pethick's 1971 booklet summed up their zeal:

> The application of holography to communications and the human environment could soon have a very great and far-reaching effect on our society. Using holography, the physical environment could be anything that man can conceive. Holography can create the future.
>
> Those interested in the medium, either as a purely aesthetic statement or for its numerous commercial applications, need not worry unduly about the economic and technical problems, as the majority of these are temporary and solvable. Holography is simple. Anyone with interest, basic information and minimum equipment can make a hologram.[43]

40. Ana Maria Nicholson, interview by author, 21 January 2003, Santa Clara, Calif.
41. Fred Unterseher, interview by author, 23 January 2003, Santa Clara, Calif.
42. Ibid.
43. J. Pethick, *On Holography and a Way to Make Holograms* (Burlington, Ont., 1971), 6–7.

Their students absorbed and transmitted the same zeal. The illustrations and layout of one of the first popular holography do-it-yourself books, *The Holography Handbook*, subliminally supported the *Whole Earth Catalog* viewpoint and style while creating a modern folktale about the technological prowess of the budding community: "How did they do this while being so poor that they often ate their food stamps before they could be redeemed? The secret lay simply in understanding some basic principles of holography, and using a little common sense. It was possible to build a holographic lab, in many ways superior to those costing many thousands of dollars, out of scrap materials! (Technocrats watch out! Do you suppose there is a hidden lesson in all this?)"[44]

Another of Cross's students wrote *Homegrown Holography*, which promoted similar ideals, interspersing freehand sketches of bearded holographers with admonitions to reject "science hoodoo" that made "common knowledge inaccessible,"

> removing it from people's mind grasp
> through specialized and secret code words
> number symbols without reference
> created by the science priestcraft
> to confuse what is and to ensure the chaos.[45]

Artist Nancy Gorglione, another follower, recalls: "Expensive lab equipment was shunned; we were taught to explore refuse containers behind industrial parks for our components. People found lasers this way."[46]

The freewheeling, practical technologies espoused by Pethick and Cross were a particularly attractive implementation of countercultural ideals and a direct reaction to orthodox holographers. The simple ideas embodied in the sand table promoted a new constituency for holography, the nonscientific artisan-amateur.[47]

Social observers such as E. P. Thompson have defined culture by its practices and function, by "what [it] does (or fails to do)."[48] The diverging occupational identities of holographers were elaborated by additional

44. Fred Unterseher, Jeannene Hansen, and Bob Schlesinger, *The Holography Handbook: Making Holograms the Easy Way* (Berkeley, Calif., 1982), 18.

45. George Dowbenko, *Homegrown Holography* (Garden City, N.Y., 1978), preface.

46. Nancy Gorglione, "Lloyd Cross," *Holographics International* 1 (1987): 17, 29, quotation on 17.

47. As one of the *Technology and Culture* referees pointed out, there are striking parallels with the philosophy and practice of the "sidewalk astronomers" organized in San Francisco by John Dobson beginning in 1968 as a democratic and empowering movement, even if no direct links can be demonstrated. Both cases are qualitatively different from more traditional amateur-professional interactions, such as sky surveys or bird counts, in which there is a clearer consensual division of labor into complementary activities and a shared philosophy of purpose.

48. E. P. Thompson, "The Long Revolution," pt. 2, *New Left Review* 9 (May–June 1961): 32.

strategies of promotion and expansion. The new breed of aesthetic holographers portrayed themselves as such by their tools (sand tables), their products (art holograms), and their social arrangements with their underlying philosophies (an eclectic mix of counterculture themes, some of which were directly opposed to the conventions of optical engineers). Schools of holography promoted this new form of collective practice that vied with the working practices of small teams such as the Willow Run holographers and the earlier artist–academic scientist collaborations. Just as the University of Michigan had produced a diaspora of commercial holographers a decade earlier, Cross's San Francisco School of Holography fostered a constituency of artistic enthusiasts who carried its philosophy far beyond the Bay Area.[49]

Orthodox holographers had amassed a record of successful research and applications through peer-reviewed technical publications. By contrast, Bay Area holographers published little aside from ephemeral publicity information. Reminiscences are fragmentary and impressionistic but ubiquitous among practitioners: a wide range of American holographers of the 1970s became tangentially or intimately associated with the San Francisco School of Holography as students or holographers, production workers for the Multiplex Company, friends, business associates, or mere hangers-on, in a loose-knit collective. Recalls Gorglione: "People carved out cubby-holes to live in; under a tie-dyed parachute tent, Lloyd lived and perfected his system of multiplexing stereograms."[50]

Yet this unconventional group and its holograms attracted widespread attention. Steve McGrew, later a major contributor to commercial holography, heard about their first multiplex holograms and, visiting in 1972, "was completely shocked; I'd never seen anybody like that before. I was extremely impressed by their creativity."[51] Physicist Tung Jeong visited in 1973, and left a few days later converted to the methods of sandbox holography. For Kenneth Haines, a former Willow Run researcher who visited the Multiplex Company with an eye to acquiring it for Holosonics, a rising player in commercial holography, Lloyd Cross was "a strange, hippy guy" with whom he didn't dare do business.[52] Emmett Leith recalled Cross as "remarkable in his way, a free-spirit scientist . . . working with artists in a kind of communal society, and making some fantastic holograms."[53]

49. More conventional private schools of holography followed in New York City (1972), Toronto (1974), and Chicago (1978). During the 1980s more schools flourished, such as L'Atelier Holographique in Paris and Richmond Holographic Studios (RHS) and workshops at Goldsmiths College in London. Several directly imported the American model; Rosemary Jackson, "Workshops: Goldsmiths College," 1980, 42/1301, MoH Collection, MIT Museum.

50. Gorglione, 29.

51. Steve McGrew, interview by Jonathan Ross, 1980, Los Angeles, Ross collection.

52. Kenneth Haines, interview by author, 21 January 2003, Santa Clara, Calif.

53. Emmett N. Leith, interview by author, 22 January 2003, Santa Clara, Calif.

Besides low-cost self-sufficiency in the style of the *Whole Earth Catalog*, the San Francisco School of Holography absorbed wider meanings for holography itself. Since the late 1960s the physicist David Bohm had mused about an analogy between holography, human perception, and physical reality itself.[54] Psycho-physiologist Karl Pribram similarly had promoted an analogy between human memory and holography.[55] These links between holism and holography resonated with Eastern and mystical elements in counterculture thinking. Rather than stressing holography's theoretical basis in communication theory and image processing, as optical engineers did, aesthetic holographers emphasized that holograms resisted a reductionist analysis: they were intensely nonintuitive and yet mind-expanding. Via such connections, aesthetic holographers had redefined the subject by the mid-1980s, transcending its original technical niches to attract wider audiences. It extended now into speculative cognitive science and cosmology. The "holographic paradigm," a notion popularized by Ken Wilber, alluded to links between psychology, cosmology, and fiction.[56] Literary critics used the hologram as metaphor for the zeitgeist.[57]

By promoting ideals espoused by the wider youth culture, the Bay Area holography community nurtured a new contingent of holographers that reacted against the orthodox practices defined by optical engineers to spawn a distinct subculture. The members of the San Francisco School of Holography consciously rebelled against centrally managed, government-funded research labs and sought to liberate the subject for nonscientist artisanal practitioners. Cross's championing of low-tech holography was gradually transformed from a counterculturally inspired theme of the early 1970s—and a reaction against his original working culture—into a more modern Californian dream in the 1980s: public-access holography. Graduates of the School of Holography became artists and teachers of holography themselves, but now promoting the subject as a means of personal expression rather than as a rejection of established values. As Nancy Gorglione put it: "The stable table took it out of the physicists' laboratories and into the hands of the people."[58]

54. See, for example, David Bohm to Dennis Gabor, 14 March 1969, MB/9, Gabor Papers, Imperial College, London; D. Bohm, "Quantum Theory as an Indication of a New Order in Physics," pt. 2, "Implicate and Explicate Order in Physical Law," *Foundations of Physics* 3 (1973): 139–68.

55. See, for example, Karl H. Pribram, "The Neurophysiology of Remembering," *Scientific American* 220 (1969): 73–86, and "Rethinking Neural Networks: Quantum Fields and Biological Data" (paper presented at the First Appalachian Conference on Behavioral Neurodynamics, Hillsdale, New Jersey, 17–20 September 1992).

56. Ken Wilber, *The Holographic Paradigm and Other Paradoxes: Exploring the Leading Edge of Science* (London, 1982).

57. See, for example, Eduardo Kac, "On Baudrillard's Text 'Hologrammes,'" *holosphere* 17 (1990): 25–26 (a discussion of Baudrillard's 1981 *Simulacres et Simulations*); Umberto Eco and William Weaver, *Travels in Hyper-Reality: Essays* (London, 1986).

58. Gorglione (n. 46 above), 29.

Despite the fluid membership of the community of aesthetic holographers, periodicals also attempted to nurture community visions. Elizabeth Nelson has observed that "from the early days of the counterculture its only viable 'institution' had been the underground press," which served the counterculture "as a communications and advisory medium . . . promoting the ideas current in the counter-culture."[59] Just as San Francisco of the late 1960s and after had specific communities whose views were represented by various local underground papers, holography produced periodicals seeking to represent, bind together, or, indeed, create communities. The same had been true for the original community of holographers, the scientist-engineers who recast optical engineering, which never generated a conventional scientific journal devoted solely to holography. For a wider range of holographers, the best-known periodical was *holosphere*, published between August 1972 and 1990.[60] For its first five years it was published as a newsletter for the electro-optical industry, but shifted focus to aesthetic holography when it was taken over by the New York Museum of Holography (MoH). The MoH and *holosphere* are striking examples of a transfer of influence between orthodox and aesthetic holography communities.[61]

Other periodicals also appeared, less widely available (seldom exceeding circulations of a few hundred) and shorter-lived, each pursuing a distinct vision of sociotechnical community.[62] The recurring problem in

59. Elizabeth Nelson, *The British Counter-Culture, 1966–1973* (Basingstoke, 1989), 103.

60. *holosphere* was published monthly until the end of 1976, and resumed publication from late 1977 under the direction of the New York Museum of Holography. Publication fell to quarterly in 1983 and, five editors and many recriminations about museum management later, ceased in 1990.

61. Although the museum sought "historic" holograms from the orthodox holographers, it focused on popularizing the medium by orienting its activities toward aesthetic applications. The individuals active in the MoH (curators, archivists, holography teachers, beneficiaries of its artist-in-residence programs, and exhibition managers) were almost exclusively drawn from the artist-artisan community. A small number of scientists having links with either the artistic or commercial worlds, notably Stephen Benton, were active as advisors or board members.

62. These included *Image Plane: A Journal of Holographic Art*, a quarterly journal founded in 1980, edited by Rick Silberman and Judith Parker at Brown University, which Silberman described as "a tool for those working and interested in exploring the art of holography . . . an open, unbiased space for free expression . . . a magnet for provocative and controversial thinking, contributing toward creating a healthy and vital holographic community" (Rick Silberman, "Artist files," 1980, 30/889, MoH Collection, MIT Museum); *L.A.S.E.R. News*, a publication of the San Francisco–based Laser Arts Society for Education and Research, which also began publication in 1980, specializing in practical details of holography and eventually outgrowing a parochial perspective on the field; *The Holo-gram*, a hobbyist's newsletter published by Frank DeFreitas of Allentown, Pa., since 1983; *Wavefront*, edited by Al Razutis and Bernd Simson in Vancouver from 1985 to 1987, focusing on critical reviews of art and business, a stance that soon alienated its funders in the arts and industry; *Holographics International*, 1987–90, founded by Sunny Bains in the U.K. as an independent and objective voice for the holography industry,

launching a successful journal of aesthetic holography was reconciling the disparate identities of the various groups involved. A shifting mixture of amateur enthusiasms, artistic concerns, research interests, and economic pressures motivated the practitioners. This absence of a stable occupational and disciplinary niche was crucial in limiting the coalescence of communities, and in extinguishing any spark of professionalism that may have been smoldering. It is ironic that the most coherent communities of holography—the early Willow Run group and the San Francisco school—were the least focused on publication.

The optical engineers, who made up the original orthodox community, remained the most economically stable group of holographers. Perhaps because of the relatively accessible funding for research and development projects from government and major industries, they have maintained an occupational momentum. The original centers of activity survived, even as optical information processing was superseded by digital computing methods.[63] Interactions between the orthodox and aesthetic holography communities were initially limited, with technological trade mediated by a handful of academic scientists. A limited amount of trade has continued between them, principally through the medium of technical meetings.[64]

Holography, in some respects typical of postwar endeavors in science and technology, was thus very unusual in aspects concerning the emergence and stabilization of its technical communities. The nascent subject first fostered the formation of a new occupation (the holographer) while radically expanding the cognitive content of optical engineering. During a period of rapid transition from military to commercial sponsorship, its practitioners defined the character and tools of their subject based on the subculture of classified research at the University of Michigan and a handful of similar centers. This first community of holographers thus evolved its practice by adapting and merging preexisting disciplinary models. By contrast, the emergence of a community of aesthetic holographers was triggered by wider cultural changes. Beginning from two specific cultural events of the late 1960s—the technological art movement and the reaction of university

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with editorial staff principally from Imperial College, London (Sunny Bains, "Editorial," *Holographics International* 1 [1987]: 4); *Holography News*, published by Reconnaissance International, 1987– , a business newsletter; *Creative Holography Index*, edited by Andrew Pepper in the U.K. from 1991 to 1994, focusing on art holography; and short-lived newsletters from museums, galleries, and practitioners' collectives, some of which moved to Web-based dissemination in the late 1990s.

63. The Willow Run Laboratories, for example, continuing off campus as ERIM after 1973, mutated into the commercial enterprises ERIM International (1997) and Veridian (1999), spun off Altarum (2001), and rebadged as the Ann Arbor division of General Dynamics (2003).

64. The most heterogeneous and seminal of these were the International Symposia on Display Holography, held triennially between 1982 and 1997 and organized by Tung Hon Jeong at Lake Forest College, Illinois.

students to classified academic research—a holographic community sensitive to countercultural themes coalesced during the early 1970s.

This bifurcation of communities was mediated by the technologies themselves. For the first generation of artists, limited access to the tools and tacit knowledge of holography had hindered their ability to apply it creatively to aesthetic projects. They consequently sought collaboration with scientists, and thus interpreted and applied the technology in ways prescribed by the science-technology community. By adopting inexpensive materials and methods, however, Bay Area holographers not only shaped the technology to make it accessible to a wider public but also linked it with deeper countercultural themes. By redefining the purpose and goals of holography, they valorized different practices, technological solutions, and cultural products. This in turn reshaped the public interaction with holography. In contrast to the corporate attempts to identify markets during the 1960s, which had involved the optical engineering community, the art holographers of the 1970s fostered a cottage industry.

The historical trajectory of holography and its technical communities cannot, then, be represented as a natural sequence of developments or a paradigm of technical progress. Two of the earliest and most important technical communities in holography to emerge, optical engineers and aesthetic holographers, self-consciously employed the technology to augment their social stability, but in distinctly different ways. Optical engineers, the first orthodox holographers, expanded their cognitive domain through new theoretical perspectives borrowed from electrical engineers, which channeled the applications and meaning of the new subject. They courted Department of Defense sponsorship, developing apparatus and procedures that promoted privileged exclusivity. Aesthetic holographers marshaled the sand table to both liberate holographic practice and extend its meanings and products.

Their equipment mirrored their social structures. The heavy granite tables employed by orthodox holographers were immovable without major investments of time, labor, and money; they required considerable social stability. In effect, the inertia of the tables echoed a certain rigidity and resistance to change in that community. Similarly, the sand table embodied the qualities of its developers: malleable and versatile, built of improvised components and materials, with a fluidity that reflected the social interactions of its artisanal users.

This technological segregation was enmeshed with political factors. Orthodox holography was buoyed up by postwar military research, while the appropriation of the subject by aesthetic holographers was founded on the social norms of the youth culture of the late 1960s and its critique of that research model. Indeed, this history illustrates how a technology itself can become intensely political in the sense described by Langdon Winner—redistributing hierarchies of power and enabling, or requiring, alternate social arrangements. Like Winner, I have argued that artifacts can configure environments, and furthermore bring into existence new communities and new practices. The sand table defined a new kind of stability, both technical and social. During a brief period it mediated a new user community and occupation (the aesthetic holographer) and enabled new products (art holograms), which in turn promoted a new interpretation of the subject itself (holography as an expression of holism, or an altered epistemology). The transitory political and cultural effects of this technological artifact contrast with the more stable examples cited by Winner.[65]

The technology of holography redistributed hierarchies of power in one other important respect. The equipment that had promoted the segregation of technical communities played a subsequent role as an independent agent or quasi agent in the sociotechnical network, in the sense developed by Bruno Latour and Michel Callon.[66] The equipment of aesthetic holography became divorced from its early schools and countercultural context. It developed a life of its own, and was taken up by individualistic hobbyists, artists, and entrepreneurs. It can be seen as an example of Latour's contention that objects can themselves be understood as actors in a sociotechnical network. The optical table, by the 1980s, represented such an autonomous actor, enabling creative expression for individuals in a range of social contexts no longer mediated by any dominant user community.

Though it buttressed technical communities, the technology of holography did not entirely stabilize them. These emergent communities of holographers struggled with an elusive disciplinary identity. Incongruously, optical engineering had been redefined but had not provided the occupational, disciplinary, and professional foundations required to support holography as a recognizably stable intellectual contour within it. Such "undisciplined" technical occupations, straddling industry, academe, and government sponsorship—and yet resisting professionalization and sometimes even occupational identification—have been discussed analytically as "research-technologies." Terry Shinn has argued that open-ended technologies that potentially fit many disciplinary niches engender "research-technologists" who resist occupational categorization. These workers form interstitial communities and pursue hybrid careers.[67] The incongruity of

65. Langdon Winner, "Do Artifacts Have Politics?" in *The Whale and the Reactor: A Search for Limits in an Age of High Technology* (Chicago, 1986), 19–39.

66. A pertinent example from a large body of work is Bruno Latour, "Where Are the Missing Masses? The Sociology of a Few Mundane Artifacts," in *Shaping Technology/Building Society*, ed. Wiebe E. Bijker and John Law (Cambridge, Mass., 1992), 225–58. For recent reviews of actor-network theory, see J. Law and J. Hassard, eds., *Actor Network Theory and After* (Oxford, 1999).

67. Bernward Joerges and Terry Shinn, eds., *Instrumentation: Between Science, State, and Industry* (Dordrecht, 2001), 1–11. Examples of such communities are common in, but transcend, the field of optics and instrumentation.

the "holistic" subject of holography, like other research-technology specialties that rely on the integration of disciplines, is that its specialists have remained dispersed throughout industry, government, and academia.[68] Aesthetic holographers, defined in response to, and in combination with, wider cultural trends, proved even more fluid and difficult to pin down. The aesthetic perspective, which discarded military, industrial, and academic connections, thus challenges the breadth of the definition of research-technology.

As a case study, therefore, holography offers an illuminating example of the nature of interactions between a nascent technology, its emergent communities, and the wider culture. The experiences of the first decade of laser holography illustrate the importance of political context and the manner in which a seemingly neutral technology can be applied in different ways to establish the identities of embryonic technical groups. It further demonstrates that this coevolution of technology and community is particularly sensitive for fields in which uncontentious success is elusive.

68. Sean F. Johnston, "In Search of Space: Fourier Spectroscopy, 1950–1970," in Joerges and Shinn, 121–41.