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# The Parallax View: the Military Origins of Holography

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## 1. Introduction

The title of this contribution is meant to evoke at least three sources. The first – and perhaps the only obvious one – concerns the ability of holograms to display *parallax*, a shifting of visual viewpoint that allows a three-dimensional image to reveal background objects behind those in the foreground. This parallax view is a unique feature of holograms as visual media. A second allusion is to the American film *The Parallax View* (1974, director A. J. Pakula), a rather paranoid thriller focusing on conspiracy theories concerning government and corporations. To a casual observer, the bare details of the military origins of holography suggest just such cynical and centrally-directed development, although I hope to dispel such simplistic ideas here. And a third passing reference is to the book *The Parallax View* (2006) by Slavoj Zizek, a wide-ranging and deep exploration of duality in political views, ontological interpretations and scientific methods, among other topics.[2]

Zizek's theme, as well as Pakula's, is relevant to my approach, which focuses on a parallax of both practice and intent. During the first successful decade of holography, conflicting viewpoints developed between distinct communities: the militarily-guided engineers who invented practical holography, and the later imaging scientists and artisans who stressed three-dimensionality and other attributes instead of the original goal of optical image processing. I have developed these ideas in a recent book that

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[2] Zizek, Slavoj, *The Parallax View* (Cambridge MA: MIT Press, 2006).

argues for different perceptions of what holography is and what it is for, according to distinct groups of users.[3]

**1.1 Origins of the hologram**

The first holograms had no connection with military goals or contexts, at least not directly. The principle of the hologram was, however, conceived by the Jewish Hungarian engineer Dennis Gabor in England, who had felt the need to emigrate from Germany in 1933 following the rise of Adolph Hitler to power. Ironically, Gabor's development projects at British Thomson-Houston (BTH), a major military contractor during the Second World War, were determined by his status as a potential enemy alien: he was excluded from BTH's war work on projects such as radar and infrared detection, and was segregated in a building outside the secure area of the company premises.

This physical and intellectual exclusion may have contributed to Gabor's attention to innovative commercial concepts. In 1947, he conceived the hologram process, a form of two-step imaging.[4] First, light of a single wavelength and point of origin (i.e. *coherent* radiation), would cast a shadow of an opaque object, a shadow ringed by bright and dark fringes owing to the diffraction of light by the object's edges, and subsequent constructive and destructive interference. This *physical shadow* or *hologram* would be recorded on photographic film. Second, the processed film would be situated in a beam of coherent light, and the fringes would diffract the light to reconstruct an image of the original object. This complicated and seemingly pointless procedure had some advantages in principle. Gabor imagined it solely with reference to the electron microscopes being developed by a sister company (AEI) during the

[3] Johnston, Sean F., *Holographic Visions: A History of New Science* (Oxford: Oxford University Press, 2006). Some of this article's cases are drawn from the book.

[4] There had been earlier expressions of two-step imaging, notably by the Polish physicist Miecislav Wolfke (1883–1947) in 1920 and by Sir Lawrence Bragg from 1939. Bragg, a Nobel Prize winner, shepherded Gabor's hologram ideas through British scientific meetings and journals, and acted as his unofficial mentor.

1940s. Such microscopes were intrinsically limited by poor-quality electron lenses; Gabor hoped that by recording the physical shadow from the coherent electron beam and then reconstructing with visible light, it would be possible to correct for the optical aberrations using high quality optical lenses, and so yield a higher-resolution image. He also suggested that this technique would allow three-dimensional imaging, or at least an image having a large depth of field.

In practice, however, Gabor's ideas were stillborn. Between 1948 and about 1955, he collaborated with AEI colleagues to generate electron microscope holograms; at BTH, and later with his doctoral students at Imperial College, London, where he became Reader in Electronics, he attempted optical recording and reconstruction of holograms. Results were poor and did not impress either his principal audience – electron microscopists – or influential optical physicists such as Sir Lawrence Bragg and Max Born.[5]

## 2. The post-war military context

Beyond Britain, the development of the hologram followed a trajectory that was more overtly shaped by military concerns.

In post-war Germany, physicists were constrained in their choice of research fields.[6] At the University of Hamburg, for example, nuclear physics was a proscribed subject until 1953, so graduate student Adolf Lohmann took up optics instead. He developed a variant of the Gabor hologram and made links – as Gabor himself had hinted in other research – with information theory, a burgeoning post-war topic.[7] Information

[5] Johnston, Sean F., 'From white elephant to Nobel Prize: Dennis Gabor's wavefront reconstruction', *Historical Studies in the Physical and Biological Sciences* 36 (2005): 35-70.

[6] See, for example, Hentschel, Klaus, *The Mental Aftermath - The Mentality of German Physicists 1945-1949* (Oxford: Oxford University Press, 2007).

[7] Lohmann, Adolf W., 'A new duality principle in optics, applied to interference microscopy, phase contrast etc.' *Optik* 11 (1954): 478-88; Lohmann, Adolf W.,

theory, or communication theory, developed during the 1950s largely within the community of electrical engineers, who themselves were motivated by research and development interests focusing on national security. This work nevertheless made little impact in the open literature of optics, which was still centred on the rather mundane field of instrumental optics.

Research along Lohmann's lines was, however, being pursued actively in other less open environments. There were two sources for this growing interest. First, wartime optical research had become more oriented toward military objectives. There was a longstanding link, extending back to the turn of the century, between military objectives and optical instruments. Government laboratories such as the National Physical Laboratory in Teddington, UK and the Vavilov State Institute in Leningrad, USSR had a responsibility for developing, testing and validating optical instruments for battlefield use. During the Second World War, collaboration between government, industry and academe had increased dramatically and demonstrated the efficacy of these arrangements, and the post-war consensus was the governments should directly fund research to meet national goals. Nationally-funded laboratories, and government-funded academic research, expanded and increasingly had a military orientation.

Second, the field of optics itself was being transformed, partly because of new national goals of military supremacy during the Cold War. With a dramatically increased availability of government funding, projects expanded to explore innovative

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'Optical single side band transmission applied to the Gabor microscope', *Optica Acta* 3 (1956): 97-9. On the rise of information theory see, for example, O'Neill, E. L., 'Spatial filtering in optics', *IRE Transactions on Information Theory IT-2* (1956): 56 and O'Neill, E. L. (ed.), *Communication and Information Theory Aspects of Modern Optics* (Syracuse, NY: General Electric, 1962). The work of a communication theorist, Peter Elias, was also seminal in promoting this general perspective; see Elias, Peter, 'Optics and communication theory', *Journal of the Optical Society of America* 43 (1953): 229.

research ideas in optics. By the late 1950s, optics was extending into the previously circumscribed domain of electronics to form a new field, electro-optics. One topic concerned the generation of radiation: the MASER (Microwave Amplification by Stimulated Emission of Radiation), followed by the LASER (Light Amplification…). Another new realm was in the detection of radiation via new forms of optical detector.[8] The expansion of optics also carried it further into the previously arcane field of *physical optics*, involving the interference and diffraction of light waves. Until the 1950s, the experience in physical optics had been confined largely to national laboratories involved with metrology: light had proved to be an ideal yardstick for measuring length and time. The newer applications, though, took this knowledge and technique into domains of more direct military value.

## 3. The construction of 'holography' for military goals

### 3.1 Stanford University

Besides Gabor and Gordon Rogers in England and Lohmann in Germany, the only workers to publish on holography during the 1950s were at Stanford University in California.[9] Stanford, an institution that had played a significant role in wartime research and development, was one centre of what American President Dwight Eisenhower subsequently called the 'Military-Industrial Complex'. The university's wartime experiences encouraged its administrators to realise the economic benefits of post-war government contract research, and Stanford rapidly spawned companies funded by such contracts and manned by its current or former academic staff. The Stanford Research Institute (SRI) was founded in 1946 to engage in non-traditional university research founded on classified contracts.

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[8] Forman, Paul, 'Inventing the maser in postwar America', *Osiris* 7 (1992): 105-34.

[9] Note that the term 'holography' was not in common use before 1966 to retroactively unite these distinct investigations; I adopt this term anachronistically merely for convenience. The earlier terms – for what were conceived as distinct subjects or techniques – were 'holoscopy' and 'wavefront reconstruction' (Gabor); 'diffraction microscopy' (Gordon Rogers); 'Gaboroscopy' (Baez), 'wave photography' (Denisyuk) and 'lensless photography' (Emmett Leith and Juris Upatnieks).

The university also formed the Stanford Industrial Park in 1951, offering long-term leases to companies on university-owned land. The first tenant was Varian Associates, the founder of which had provided the initial idea for the optical processing of synthetic aperture radar data. Through the 1950s, other research operations were founded there to conduct research and development in electronics or optics, including General Electric, Eastman Kodak, Admiral Corporation, Shockley Transistor Laboratory of Beckman Instruments, Lockheed, and Hewlett-Packard. By the 1960s, the rapid growth of electronics and optics firms south of the Bay Area of San Francisco became known as Silicon Valley.

At Stanford, physicist Paul Kirkpatrick led his doctoral student Hussein El Sum and former student Albert Baez to explore Gabor's 'wavefront reconstruction'. Kirkpatrick's principal aim was x-ray astronomy, but his students found employment further afield. El Sum later worked at military contractor Lockheed Aircraft, promoting holographic applications and particularly the acoustic holography of interest to the American Navy; Baez pioneered the teaching and researching of holograms with undergraduates.[10]

### 3.2 The Vavilov Institute

The other side of the Cold War generated a complementary view of holography during the late 1950s.

The Vavilov State Optical Institute (GOI, according to its Russian acronym) was founded in 1918 in Leningrad as a model institution by the new Soviet Commissariat of Education. By the 1920s it became the largest optical research centre in the USSR and one of the best equipped institutes in the country. From the end of the First

[10] Incidentally, Baez's daughter Joan became a folk singer and student activist during the 1960s, following the family's residence in Cambridge, Massachusetts when Albert Baez worked at MIT.

World War, then, the Vavilov Institute had grown to become a highly coherent optical research and production centre without parallel in either Europe or America. Such centres had first received a strong international impetus at the turn of the century, when manufacturing standards became recognised as crucial to national economies and foreign trade, and again during the First World War, when the weaknesses in national optical industries were identified. Yet, the intensive concentration on all aspects of optics – particularly the combination of physical optics, spectroscopy, and emulsion chemistry – made the GOI quite unlike state organizations in other countries.

Renamed the S. I. Vavilov Institute after the Second World War in recognition of one of its most prominent scientists and administrators, it expanded to become the largest optical institution in the world. This growth satisfied national aspirations. After the war, most branches of science and technology that had military orientation or applications received high state priorities in the Soviet Union. The Academy of Sciences established new research institutes and, as in the west, the direct government funding for science increased dramatically. The Academy grew to an enormous and complex organization that dominated not only the pure sciences, but the applied sciences and technology as well.

This environment fostered advanced study as well as innovation. Unlike their American and British counterparts, most practising Soviet scientists were associated with a research institute, and senior research workers were also affiliated with universities for teaching and supervision of research students. Zhores Medvedev characterizes scientists and technologists during this time as the new privileged elite. The number of students nearly doubled compared to the pre-war levels and 'almost all demobilized soldiers who had a secondary education were absorbed by the enlarged network of higher technical schools and universities'.[11]

[11] Medvedev, Zhores A., *Soviet Science* (Oxford: Oxford University Press, 1979), p.44.

One such worker was Yuri Nicholaevitch Denisyuk, who joined the Vavilov Institute in 1954 following completion of an engineering degree. Denisyuk spent most of his time on Navy-related work, 'occupied', as he later recalled, 'with very dull work relating to the development of conventional optical devices consisting of lenses and prisms'.[12] Besides orthodox instrumental optics, however, he also worked then and for much of his subsequent career on more advanced branches of optical technology having military significance, such as systems of stellar navigation for submarines, and on synthetic aperture radar, subjects also being actively investigated by American counterparts.

Denisyuk, in common with many Soviet research workers, pursued an advanced *Kandidat* degree, selecting for his research topic investigations of novel forms of imaging. His early explorations in the late 1950s followed the path of French Nobelist Gabriel Lippmann, and he developed a technique of recording a *reflective* hologram – dubbed by him a 'wave photograph' – quite unlike that of Dennis Gabor in concept and properties. His work, published from 1961, went largely unnoticed at home and abroad in part because of his lack of connection to the Soviet professional network, in part because of his limited practical results, and in part because of the disorienting novelty of his concept.

### 3.3 The Willow Run Laboratories

The ideas that developed into holography sprouted independently in a third location, Michigan at about the same time. On a scale unmatched by British Thomson-Houston and the Vavilov Institute, the University of Michigan was awash with targeted research funding by the late 1940s. Fresh from a record of successful applied research during the war and during the early months of the Cold War conflict, the American War Office decided to continue funding research and development projects at universities during peacetime – a development welcomed by Stanford University, as already noted, and by the University of Michigan.[13]

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[12] Denisyuk, Yu N., 'My way in holography', Leonardo 25 (1992): 425–30, p. 425.

[13] The support of American physical science by agencies devoted to military needs has been estimated as 90% of all funding for the post-war decade [Kevles, Daniel J.,

Immediately following the war, two professors in the Electrical Engineering Department proposed a large-scale research project to develop an antiballistic missile system. Financed by the Department of Defense (DoD), the university founded the Michigan Aeronautical Research Center (MARC) at the nearby Willow Run Airport.[14] From the late 1940s, other University of Michigan (U-M) laboratories were founded there and supported principally by Air Force contracts. The location suited its function: situated some 15 miles from the Ann Arbor campus, Willow Run intellectually and physically isolated its workers. The requirements of classified research contrasted with traditional academic openness, and in some respects mirrored the much more established Vavilov Institute. No academic teaching took place on the site, although some of the staff held dual appointments as academics in the Department of Electrical Engineering. Through the 1950s, increasing numbers of graduate students worked and undertook thesis projects there. As groups and funding mushroomed, the 150 acre site was renamed the Willow Run Research Center and, later still, the Willow Run Laboratories (WRL).

The subjects investigated by the Willow Run workers covered a wide array of new technologies conceived during the war. They included radar, infrared, acoustics, optics, guidance, and data processing. An early digital computer design, the Michigan Digital Automatic Computer (MIDAC), was developed there. So, too, was the first

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*The Physicists: The History of a Scientific Community in Modern America* (Cambridge, MA.: Harvard University Press, 1995)]. On the arguments behind the government funding of research, see also Wang, Jessica, *American Science in an Age of Anxiety: Scientists, Anticommunism, and the Cold War* (Chapel Hill; London: University of North Carolina Press, 1999) and Zachary, G. Pascal, *Endless Frontier: Vannevar Bush, Engineer of the American Century* (New York; London: Free Press, 1997).

[14] The Boeing-Michigan Aeronautical Research Center (BOMARC) surface-to-air missile began testing in 1952 and was operational between the late 1950s and early 1970s.

ruby maser. The Laboratories also presented summer schools for the growing community of military-contract researchers around America, and so became a locus for the developing expertise in these classified fields.

One of the areas under investigation at Willow Run was development of a variant of imaging radar that became known as Synthetic Aperture Radar (SAR). The DoD awarded Willow Run PROJECT MICHIGAN – the university's largest research contract – to investigate technologies of battlefield surveillance, of which SAR was a promising possibility. Members of the new Radar Lab at Willow Run began to develop electronics for the radars and schemes for processing the data into an optical image. Electronic computers of the day were too limited to undertake this task, so a sub-group within the lab pursued the possibility of optical processing of radar data. Of the hundreds of technical workers who found employment at Willow Run, one of the first to become involved with the Radar Laboratory investigations was Emmett Leith. Raised and educated in Michigan, Leith joined as a Research Assistant in 1952. Having taken four standard undergraduate optics courses as a Physics student – in physical optics, two in spectroscopy, and in x-rays and crystal structure – he found himself well placed in an environment dominated by electrical engineers to investigate optical processing.

Over the following eight years, Leith and his colleagues gradually evolved ways of thinking about the problems of synthetic aperture radar that merged the concepts of electrical engineers and optical physicists. They converged on information theory and optical information processing, ideas that had been touched upon by Gabor a decade earlier, but pursued them relentlessly at Willow Run to yield practical goals. The result was a successful SAR system in 1960 that converted engineers almost overnight to this new hybrid discipline (Figure 1 shows a SAR image of the Willow Run Laboratories themselves).

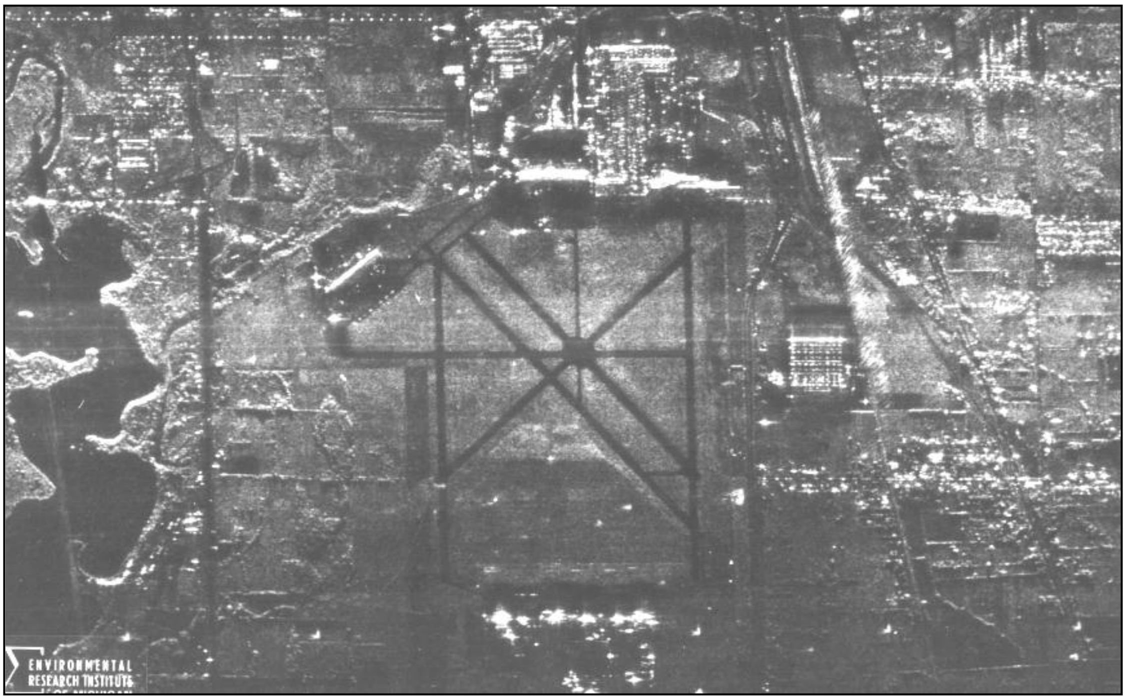


**Figure 1: Synthetic Aperture Radar (SAR) image of the Willow Run Laboratories** (located top centre, above runway). Courtesy of E. Leith.

An unexpected side-effect of this research was that, in 1956, Leith realised that his independently developed theory and implementation of the optical processing of imaging radar had certain similarities to Gabor's electron microscope holograms. From 1960 onward, Leith and a new colleague, Latvian immigrant Juris Upatnieks, were able to devote some of their time under their classified contract budgets to further develop holograms, basing their research on their mastery of optical image processing. To improve their results, they sought a windowless lab having improved foundations, and moved to a building – the 'blockhouse' – that had been constructed as the control centre of the BOMARC missile defence project (Figure 2).

**Figure 2: The ‘blockhouse’, site of the invention of Leith-Upatnieks holograms.** Note the military jeep and test radar in the background. Courtesy J. Upatnieks.

By 1961 they had devised an elegant theoretical solution to Gabor’s unsolved optical problems, and one that yielded eminently practical results: crisp and flawless optical reconstructions of two-dimensional black and white line drawings. A year later, their research provided grey-scale reconstructions of two-dimensional photographs, aided by the new availability of helium neon lasers. But, in late 1963, lasers permitted their most spectacular achievement: reconstruction of three-dimensional images of solid objects. Over the following few months, news circulated between their Willow Run colleagues, local suppliers and contract administrators.

### 3.4 Camouflaging military foundations

At U-M, holography struggled to escape the velvet handcuffs of military sponsorship. On the one hand, research contracts were readily available; on the other, the free dissemination and wider application of the technology were not actively encouraged. This dramatic technology had had an almost imperceptible rise to prominence. The reason for this was not an overt intention to restrict access to holographic developments, but merely the context of classified research: the engineers and administrators were conditioned to keep quiet, and the novelty of the invention meant that even close colleagues were unfamiliar with the technology and its possible benefits for wider society. The conference presentations and scientific papers of Leith and Upatnieks before 1963 – all restricted to classified audiences – had made little immediate impact on colleagues back at Willow Run.

Nevertheless, as Leith subsequently recalled, 'reticence was the byword': those early papers on wavefront reconstruction had to be approved by the military agency that sponsored their work, a process that introduced a delay of several months even before the papers' refereeing by scientific journals.[15] The material, which was outside their previous experience, may well have baffled the military personnel who reviewed it. The Radar Lab's director, William Brown, recalled:

> While there was some excitement about it, there perhaps wasn't as much as there should have been. While it looked like an excellent piece of coherent optics work, from a technical standpoint we couldn't be sure whether we had an important scientific tool on our hands or just a curiosity.[16]

But the new research on holograms had to be filtered from its classified source. This had been apparent in 1960, when the successful SAR system (the 'AN/UPD-1 High-resolution Radar Combat-Surveillance System') was announced: the Willow Run personnel were prevented from drawing attention to the link between radar and optical processing. The key papers concerning the method appeared in the open literature only years later. The newspaper coverage was coy, providing welcome recognition for their achievements but, as Leith recalls, obscuring the close association with classified research:

> One thing that was a real pain, a real sticker, was the association of optics and radar; that was secret. If you worked in optics, you couldn't mention radar, and the other way around; it didn't work. And there

[15] Leith, Emmett N. to SFJ, email, 11 Mar. 2003, Ann Arbor, SFJ collection.

[16] Wolff, Michael, 'The birth of holography: a new process creates an industry', *Innovations* (1969): 4-15, p. 7.

> were some nasty anecdotes […] I worked in radar, and therefore I couldn't write about optics, but the other guys, who didn't work in radar, could. They worked in radar too, but they just didn't write papers [. . .] You could talk about one or the other, but not both in the same breath.[17]

Leith himself remained cautious in revealing information to his peers, partly because of his continuing career in classified research and partly because he was fending off unjustified priority allegations from a senior colleague in the U-M Electrical Engineering Department, Prof. George Stroke, a rival who deployed publications effectively to make his claims.[18] Leith was particularly careful in dealing with foreign enquiries: in 1965 – fifteen months after the announcement of 3D holograms – he wrote to Gordon Rogers, who had researched Gabor's holograms in Britain a decade earlier, that 'since our more recent work is not being done on a military contract, I have been sending copies of them out of the country'.[19] Leith did not make direct contact with Dennis Gabor himself until 1965; he first fielded questions from Russian investigators in 1966, and hesitated to speak to Soviet workers at his first conference in the nation in 1973.[20]

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[17] Leith, Emmett N., Donald Gillespie and Brian Athey to SFJ, interview, 11 Sep. 2003, Ann Arbor, SFJ collection.

[18] Johnston, Sean F., 'Telling tales: George Stroke and the historiography of holography', *History and Technology* 20 (2004): 29-51.

[19] Leith, Emmett N. to G. L. Rogers, letter, 6 Jul 1965, Imperial College Archive, ROGRS 4.

[20] Ostrovskaya, G. V. and Y. I. Ostrovsky to E. N. Leith and J. Upatnieks, letter, 13 Sep. 1966, Leningrad, Leith collection. Security concerns gradually declined, however. Leith and Denisyuk had first come into brief contact at the 1973 Novosibirsk meeting. In 1979, Leith was invited to visit the Soviet Union as the guest of the A. F. Ioffe Institute, visiting important centres of Soviet holographic research: the Ioffe Institute itself and the Institute of Nuclear Researches, both in Leningrad, the P. N. Lebedev Physical Institute, the Research Kino-Foto Institute (NIKFI) and the

From 1963, though, Leith and Upatnieks were catapulted from the hidden world of military contract research to the public stage. The Optical Society of America publicised their conference paper, presented in April 1964, as 'lensless photography'. In contrast to the lack of interest as recently as a year earlier, their employers were now attentive. The new Director of the Willow Run Laboratory was cooperative in accommodating the research and sought funding and patent coverage from the Battelle Memorial Institute of Columbus, Ohio – an unusual development that transplanted the classified research into the commercial realm. Leith recalled the buoyant response:

> We got research funds. First of all the Air Force threw money at us, just to explore it for applications. They gave us $150,000, which was a big chunk of money at that time, just to hunt for applications, and it wasn't really a classified contract, this was a side line from the radar work we'd been doing as we went along, so this was a welcome thing, then the Battelle people gave us some money, so we had a lot of good funding.[21]

Even so, three-dimensional holograms were slow to make an impact beyond Willow Run. The first published descriptions of three-dimensional imagery appeared inconspicuously in the magazines *Electronics* and *Science Fortnightly* at Christmas

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Institute for Information Transmission Problems, both in Moscow, the Physico-Technical Institutes in Kiev and Riga, and the Institute of Automatics and Electrometry in Novosibirsk. Leith and Denisyuk met again at a Soviet holography conference in Leningrad, with Leith and his two daughters visiting Denisyuk's family and the Vavilov Institute, although not Denisyuk's laboratory owing to security concerns. Denisyuk himself made his first trip to America in 1989, after the end of the Soviet Union, and subsequently made more frequent visits to Western countries. During his second visit to Ann Arbor in 1989, he travelled by car with Emmett Leith on an 800-mile conference trip, with stops at Niagara Falls and the Adirondack mountains. The two, having travelled the same road half a world apart, could do so together at last.

[21] Leith, Emmett N. to SFJ, interview, 22 Jan. 2003, Santa Clara, CA, SFJ collection.

1963, barely three weeks after Leith and Upatnieks had achieved their first successes with 3D holograms, and only a few days after their first high-quality results. With impressive holograms to show off, the news about three-dimensional imaging during the winter of 1963-4 began to raise the profile of their latest research, something that had not occurred at Willow Run since the announcement of the SAR system in 1960:

> It was a type of imagery that had never before been seen. People sat up and took notice, people in the laboratory looked at it in astonishment, the management came in and looked at it, and the Director came in, people outside the university came and looked at it.[22]

Over those first months, word-of-mouth accounts of visitors and reports in the popular press began to raise attention around Ann Arbor. But the galvanizing event was the presentation at the 1964 Spring meeting of the Optical Society of America, held in Washington DC. At the final session on "Information Handling by Optics", Juris Upatnieks described their latest work. In lucid language divorced from any specialist jargon and concepts, he announced optical characteristics that surprised many practicing physicists: experimental evidence that a ground glass plate would not destroy optical coherence, and the creation of a reconstructed image that was dramatically superior to conventional stereoscopic images, evincing the properties of parallax, focus at different planes and binocular depth. The optical phenomena raised questions for all optical scientists, ranging from the properties of laser light, to imaging and emulsion properties, to the nature of stereoscopic vision. The abstract described a change of perspective – a parallax view – in more than one sense. Leith has noted retrospectively that 'the abstract, more than any other document, including the papers and the news releases, […] set in motion the great explosion in holographic activity'.[23]

[22] Ibid. Despite security measures for classified research at WRL, it was not uncommon for visitors to have relatively easy access to the site.

[23] Leith, Emmett N. to SFJ, email, 4 Mar. 2003, Ann Arbor, SFJ collection.

### 3.5 Military origins of commercial holography

Spreading the word was initially slow because Willow Run, and even the University of Michigan, were in a peculiarly detached environment. Ann Arbor, the leafy town in which the U-M was based, had, like Stanford University, benefited increasingly from government research contracts during the 1950s. The city had begun to develop an industrial base owing to the heavy government investment in research and development contracts with the University of Michigan. Strand Engineering (1955) was one of the first firms to appear, followed by Parke Davis (1958), the Bendix Corporation, Federal-Mogul, and Climax Molybdenum. By 1969, fifty-eight research and development companies, employing some 3000 persons, were located there. During the same period, the government research funding at the University of Michigan nearly quadrupled to $62.4 million annually.[24] Local businesses were supported by, and catered increasingly to, government contracts. As a direct result, Ann Arbor's commercial holography was firmly rooted in classified research. The majority of personnel, firms, equipment choices, procedures, and outlook—in short, the technical culture – derived directly from the classified concerns of Willow Run.

Alongside the explosion of research at established institutions, enthusiasm sprouted in start-up firms. The university's diverse activities in optics and infrared research provided the requisite skills and personnel to found some of the first companies to exploit commercial holography during the 1960s. As a result, the early commercial take-up of holography blossomed in Ann Arbor. And, unlike some other centres of technical expertise, Ann Arbor's commercial holography was firmly rooted in classified research.

The first and most important early commercial explorations of holography's potential were made at the Conductron Corporation. The company had been founded in 1960 by Keeve M. (Kip) Siegel, an engineer-entrepreneur who still headed the WRL Radiation Laboratory. Conductron's employees, and those of two subsequent

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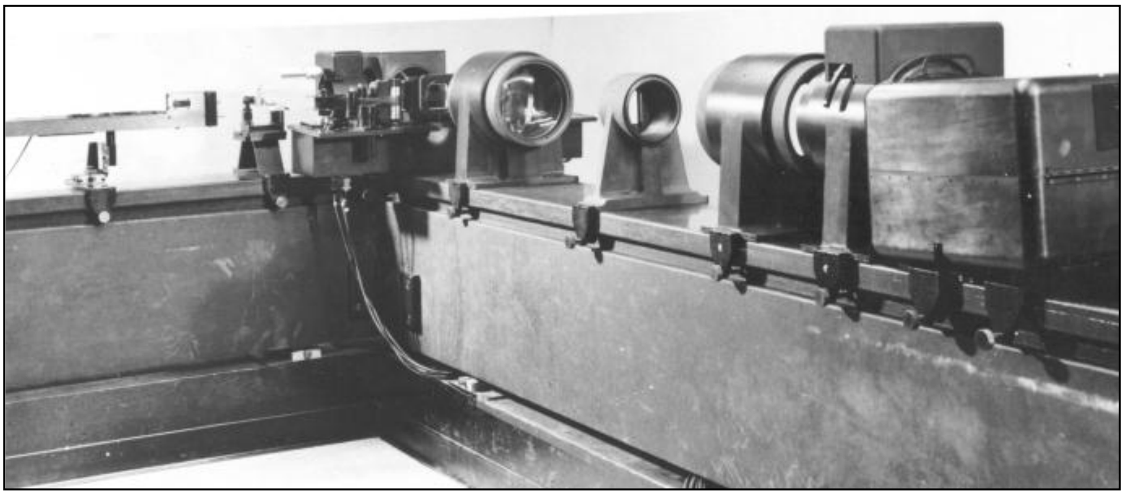
[24] Anon., 'Many holographic roads lead to Ann Arbor', *Laser Focus*, February 1969: 16–7.

companies founded by Siegel in Ann Arbor, KMS Industries and KMS Fusion, were cross-fertilized by employees who joined his new ventures.

Supported by lucrative military contracts during the early 1960s, the Conductron Corporation also took up holography, and by the same route that Leith was drawn to it: via synthetic aperture radar. The two originators of the Willow Run SAR optical processing work, Lou Cutrona and Wes Vivian, joined Conductron in 1961 to oversee such contracts. Cutrona built up expertise at Conductron that mirrored the expertise within the WRL Optics Group, hiring a physics graduate and part-time WRL employee, Gary Cochran, in early 1962 to work on SAR optical processing. Working independently of Willow Run, Cochran's group developed expertise in similar areas (Figure 3).



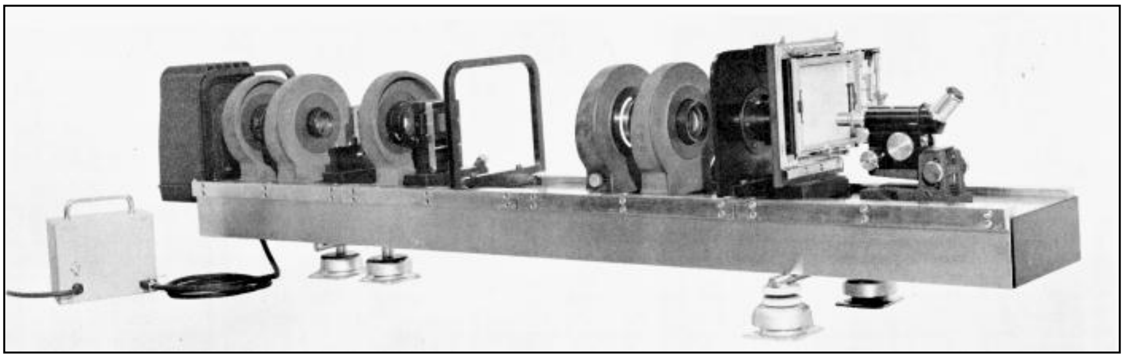


**Figure 3: Willow Run (top) and Conductron (bottom) optical processing apparatus.** Courtesy E. Leith (top) and G. Cochran (bottom).

Because Conductron was working on the optical processing of SAR data just as Leith and others were doing at Willow Run, Cochran had suitable equipment and background for holography. Kip Siegel was fascinated by his first view of a hologram, and Cochran recalls that Siegel wanted especially to develop the technology as a tool of investment.[25] A former WRL employee who founded a holography equipment company recalled chatting with Siegel about business:

> I told him, 'I finally understand how to make a million – don't sell technology to scientists – sell technology to consumers!' Kip said, 'No, you've got it almost right; what you've got to do is sell the *promise* of technology to *investors*'.[26]

Activities at Conductron focused on this goal, modelled closely on successful strategies for winning contracts with the DoD. Cochran's group began making bigger and better holograms from early 1965, and the growing variety of demonstration pieces was also used to attract commercial interest, culminating in the sale of the company to McDonnell Douglas, which saw potential in holography for creating aircraft simulators.

Another early local success was GC Optronics, a 1966 spin-off company of U-M engineers Ralph M. Grant and Joseph Crofton, who developed a technique for employing holography to detect flaws in pneumatic tires and for spotting unbonded regions between honeycomb sandwich panels, particularly valuable for the lucrative aircraft market, both civil and military. Their start-up phase, like much of the research in the university's Electrical Engineering Department, was funded by Navy contracts.

**4. Reaction to military orientation**

By the late 1960s, some five years after the first publicity of laser holograms, holography was dominated by military and corporate funding in America. It was of particular interest to the aerospace industry, which straddled civil and military

[25] Cochran, Gary D. to SFJ, interview, 6 and 8 Sep. 2003, Ann Arbor, MI, SFJ collection.

[26] Gillespie, Donald to author, interview, 29 Aug and 4-6 Sep, 2003, Ann Arbor, MI.

interests. This clear association was self-fertilising – leading, for a time, to an explosion of exploratory research under classified and NASA contracts – but also created a backlash.

### 4.1 Student anti-war organisation

The dominant culture of holography during the 1960s had been that of post-war science, largely allied to contract research in university, government, or corporate laboratories. Popular understanding had developed about what modern science entailed: it was an esoteric, intellectually progressive, elitist and well-funded activity, and having wide economic and intellectual value. Downplaying its military origins, newsreel and television stories presented this culture as one of neck-tied and disciplined male physicists working in a clean laboratory environment among powerful lasers and expensive optical equipment. Yet this conventional public image did not capture the enthusiasm engendered by modern optics. That fascination was largely shielded from the public, and young post-war audiences gradually developed a negative evaluation of modern science.

The growing distance between 'big-science' holography – funded directly and indirectly by classified government contracts – and wider culture is illustrated by the rising student protests in America during the late 1960s. Ann Arbor was home not only to the Willow Run Laboratory and classified optical research, but also to the Students for a Democratic Society (SDS), an influential organisation of politicised students that was to flourish on a number of American campuses. While these two events had no initial correlation, their proximity soon became significant. SDS had been established in 1959 by Alan Haber, a sometime Ann Arbor student, from the youth branch of an older organization for socialist education, the League for Industrial Democracy. Fifty-nine founding members held the first meeting in Ann Arbor in 1960, and two years later the fledgling group adopted the 'Port Huron Statement', a political manifesto written principally by Tom Hayden, former editor of the University of Michigan (U-M) student newspaper. The group called for a more participatory form of democracy to address the social problems of racism, poverty, materialism, and militarism. As early as October 1963—when Leith and Upatnieks were about to begin their first successful experiments with three-dimensional holography—a large student rally on campus protested American intervention in Indo-China. Ann Arbor's SDS chapter was the largest one in the country during those early years.[27]

SDS and the 'Free Speech Movement' (formed at the University of California at Berkeley in 1964 to protest against heavy-handed actions by their university administrators) became the core of the New Left, part of the wider youth movement dubbed the 'counterculture' by social analysts of the 1960s. In March 1965, Liberal Arts faculty members at U-M organised the first 'teach-ins' in conjunction with students' 'sit-ins' to discuss issues surrounding the war, an activity soon taken up and repeated at dozens of other campuses. The SDS opposition to militarism became more focused on protest against the Vietnam War from January 1966, when the Johnson presidential administration ended automatic student deferments for the draft. SDS membership mushroomed when the National SDS Convention was held in Ann Arbor that year. The tempo of protest increased year by year, broadening its philosophy and further politicising its stance. In 1969 some twenty thousand persons protested the war at the city's Michigan Stadium. An extreme faction, the Weathermen, developed from the splintering of SDS that year, going underground and adopting more militant tactics against establishment targets and specifically activities supporting the Vietnam War. Ann Arbor had become not only a major centre for classified research, but also a focus for political activism.

In this way the U-M at Ann Arbor, and more specifically the Willow Run Laboratories (WRL), became a focus for student protests through the 1960s. In 1967

[27] Unger, Irwin and Debi Unger, *The Movement: a History of the American New Left, 1959–1972* (New York: Dodd Mead, 1974). On the youth movement and the role of students at Ann Arbor, see also Breines, Wini, *Community and Organization in the New Left, 1962–1968: The Great Refusal* (New York, NY: Praeger; J.F. Bergin, 1982) and Bunzel, John H., *New Force on the Left: Tom Hayden and the Campaign Against Corporate America* (Stanford, CA: Hoover Institution Press Stanford University, 1983).

a sit-in at the U-M Administration building protested the university’s classified research at Willow Run and the Radar and Optics Laboratory, recently moved to the town’s North Campus; this helped to spearhead protests by students at over a hundred American campuses against the war and against local militarily funded research over the following year. Even more directly, the IST building was bombed one autumn night in 1968, destroying the door and windows of the Radar and Optics Lab along its east wing (Figure 4).

**Figure 4: Bombed windows and doors of Emmett Leith's holography laboratory at the University of Michigan, October 1968.** Courtesy C. Leonard.

In response to such protests, the university administrators debated whether to absorb WRL into the College of Engineering to submerge its identity, or to affiliate it with an independent non-profit organization such as the Battelle Memorial Institute. Research funding from military sponsors had fallen from a peak of $13 to $9 million in 1969. The Director of WRL, and spokesmen for individual laboratories at Willow Run reported to the press that they saw campus unrest concerning classified research as a major cause for uncertainty about future financing of contracts by the Defense Department, citing specifically the SDS and the Radical Caucus, ‘which are campaigning against performance of classified research at universities'.[28] A Detroit newspaper reported:

> Willow Run labs, which thrived during the 1950s on open ended research grants, have been compelled to seek contracts for specific projects whose aims are defined in advance. Moreover, there seems to be a serious morale problem at the labs, stemming mainly from the classified research controversy which began in 1967 and culminated in a report recommending guidelines for secret research and the establishment of a classified research committee to review contract proposals submitted by lab researchers [. . .] It has been distressing beyond words for the researchers to find themselves looked down upon as being involved in an 'evil' business.[29]

Holographic research in Ann Arbor became a fugitive activity. In 1972, the continuing student opposition convinced the university to opt for the extreme solution: the Willow Run Laboratory as a whole was to be reorganized as a not-for-profit company called the Environmental Research Institute of Michigan (ERIM), and moved at the end of the year to the former Bendix building a half-mile from North Campus in Ann Arbor, where the Apollo Lunar Rover had recently been developed. Carl Aleksoff, who had worked at Willow Run as an undergraduate summer student, completed his PhD at U-M and joined ERIM a few months after the move; he recalls:

> It turned out to be a surprise to everybody that it was called the Environmental Research Institute of Michigan because it was supposed to be called the *Research* Institute of Michigan, and the signs were getting ready with R-I-M—'Rim'. But we needed an endorsement from the State of Michigan [. . .], and there was one state senator that was pushing the bill through the state legislature to form the company, and he decided at that time that 'environmental' was a very good thing to have, it could help pass a bill very quickly; it was the 'in' word to use [laughing], a popular term, so 'environmental' got stuck on the

[28] 'Labs' fate linked to ROTC', *Ann Arbor News*, 10 Dec. 1969, p.1.

[29] 'Willow Run future', *Detroit Daily News*, 4 Dec. 1969, p.2.

> front and it passed, and to everybody's surprise we were the Environmental Research Institute of Michigan![30]

Some staff retained dual roles: Emmett Leith, for example, remained a professor in the Electrical Engineering Department while also consulting at ERIM as Chief Scientist, an association that was later to draw further protests.[31] Juris Upatnieks remembers:

> 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 US Congress prohibited the Defense Department from funding research that was not of direct interest to the military. Also, NSF [the National Science Foundation] funded basic research only at educational institutions. These events limited what we could do at ERIM.[32]

Thus the researchers at WRL/ERIM found their relatively unfettered research style of the early 1960s increasingly constrained by Congress on the one hand, and student protests about this classified research on the other.[33] This conflict between sponsors

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[30] Aleksoff, Carl to SFJ, interview, 9 Sep. 2003, Ann Arbor, SFJ collection.

[31] Gates, Max, 'Holography a "re-creation of reality" – defense debate', *Ann Arbor News*, 18 Mar. 1982, p.2. A group called Science For the People protested Leith's involvement at ERIM when he took part in the university's highest honour, the Henry Russel lecture. Over the next couple of years, the Radiation Laboratory at Willow Run was also the focus of student protests about military contracts.

[32] Upatnieks, Juris to SFJ, email, 15 May 2003, SFJ collection. Even so, Upatnieks remained immersed in this technical culture: his principal invention at ERIM during the 1980s/90s was a holographic gun sight, initially marketed to the military but later modified for use by sportsmen.

[33] This was not solely an American phenomenon. When Dennis Gabor lectured in Munich in 1969, he was reproached for his participation by students protesting the military-industrial complex and its visions of the future. Unlike other speakers, however, an observer later explained, 'Gabor is clean. He is as pessimistic about the

and interest groups, and their separate perceptions of the purpose and application of research in holography, was an important factor encouraging the growth of distinct communities in specific locales. Ann Arbor's unusual situation, with its concentration of holography researchers, on the one hand, and students opposing militarily related technologies, on the other, was bracketed by two other American centres: the Bay Area of California, and Boston on the opposite coast.

Stanford Research Institute (SRI) was one element in the redefinition and confrontation of cultures in the Bay Area. Student protests in the spring of 1969 centred on the SRI research. Several hundred students occupied the Applied Electronics Laboratory at Stanford. During the occupation, some 8000 faculty and students met and agreed almost unanimously that classified research at the university should end. Two weeks later, the university Trustees voted to sever Stanford University's ties with SRI. As was to happen with at Willow Run three years later, the classified research was not strictly controlled as the students urged, but merely dissociated from the university campus. Joe Goodman recalls that his Stanford holography research group, long supported by the Air Force and Office of Naval Research (ONR) disbanded when Stanford decided to leave the classified research arena.[34]

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future as the students' [Edson, Lee, 'A Gabor named Dennis seeks Utopia', *Think*, (January-February 1970): 23–7]. Gabor's books on science and society [Gabor, Dennis, *Inventing the Future* (London: Secker & Warburg, 1963; Gabor, Dennis, *The Mature Society* (London: Secker and Warburg, 1972)] unfashionably questioned the widespread confidence in technological progress and technocracy, a theme taken up more overtly by cultural historian Theodore Roszak [Roszak, Theodore, *The Making of a Counter-Culture: Reflections on Technocratic Society and Its Youthful Opposition* (London: Faber 1970)]. Nevertheless, Gabor espoused an elitist intellectual view of society at odds with what he characterised as the permissiveness of the counterculture.

[34] Goodman, Joseph W., 'Research in Holography at Stanford: 1960's 1970's and 1980's, unpublished report, SFJ collection, 30 Aug. 2005; Goodman, Joseph W. to SFJ, email, 31 Aug. 2005, SFJ collection.

On the American east coast, the Massachusetts Institute of Technology also garnered increasing student criticism for its engagement in classified research. Its town – Cambridge, across the Charles River from Boston – was also the home of Polaroid Corporation (itself a major consultant for classified research), and was dense with military contractors. An experienced reconnaissance camera design team from Boston University, for example, had formed the Itek Corporation in the late 1950s, which was to define the camera concept of the first spy satellites. The Boston University Optical Research Laboratory (BUORL) had a genealogy extending back to military funding during the Second World War.

**4.2 Holography as anti-war counterculture**

Student opposition in Ann Arbor, Boston, and the San Francisco Bay Area fostered a counterculture that had direct repercussions for holography. The student protests against classified research and, more broadly, against 'establishment' technologies and assumptions, provided a critique of holography itself. Their stance attacked particular centres such as the U-M, Stanford University, and MIT, their funding, and the nature of the research itself. More subtly, the anti-technological perspective and esoteric philosophies attaching to the youth movement urged a re-evaluation of the uses of holography.

A locus for this perspective, seminal in synthesising this new technical counterculture, was Lloyd Cross. A former WRL engineer and laser company founder in Ann Arbor, Cross became associated with artists and 'crafters' during the late 1960s, and operated a gallery and a print and framing shop in town. He met Canadian sculptor Jerry Pethick in early 1967, and the two began to explore holography together. Their group held the first exhibition for laser art and holography, *The Laser: Visual Applications*, at the nearby Cranbrook Academy of Art in suburban Detroit in November 1969 and created a small company, Editions Inc, to produce holograms and travelling laser light and sound shows around the American north-east. Their peregrinations took them to New York and then to San Francisco in 1971, where they founded the San Francisco

School of Holography, a technological commune that intersected with expanding youth culture.

Having little money for equipment, Cross and Pethick devised the holographic 'sand table', a cheap system that mechanically isolated optical components on a rubber inner tube. Their apparatus was designed to use inexpensive surplus components and tension design principles first introduced by Buckminster Fuller. Cross later reflected that his orientation 'was not so much anti-technology as against the process and procedures of technical innovation which separate and isolate the technical specialities'.[35] His goal was to mutate technology for new purposes and new audiences, and had the effect of transcending disciplinary boundaries and reducing the distance between expert and layperson.

**Figure 5: Lloyd Cross, guru of the counterculture San Francisco School of Holography and the Multiplex Company, c1975.** Courtesy A. Naeve.

[35] Cross, Lloyd to SFJ, email, 25 Oct. 2003, SFJ collection.

This design philosophy dovetailed with west-coast youth culture. It evoked the *Whole Earth Catalog*, a counterculture collection of tips, sources, and views published yearly from 1968. The small organisation was located in Menlo Park, some fifteen miles southeast of San Francisco and two miles from Stanford University. In common with the aims of the San Francisco School of Holography, the publishers described the purpose of *Whole Earth* 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'.[36] The *Catalog* was filled with an eclectic assortment of tools, book reviews, poetry, and observations on science, technology, philosophy, sociology, politics, and more. It reflected the youth movement's growing themes of individualism, alternative technologies, holistic perspectives, and opposition to authority, particularly military authority.

These perspectives were also nurtured in a specifically visual form by interactions with a growing Bay Area concentration of video artists and artisans. Lloyd Cross and Jerry Pethick contributed information and articles for *Radical Software*, a journal that sought to alter both culture and the future via communications technologies. The journal had been founded in 1970 by a collection of artists, writers, musicians, and filmmakers. They argued that the dissemination of information outside the usual commercial media channels could transform social power structures. The subjective, homemade style of *Radical Software* mirrored that of *The Whole Earth Catalog* and the ethos of the San Francisco holographers. As David A. Ross later summarised their motivations,

> Technology might have brought us to the brink of global destruction, may have enabled the alignment of power and money that kept us on the verge of devastation, yet technology was not our enemy. In fact, if

[36] Brand, Stewart, *Whole Earth Catalog–Access to Tools* (Menlo Park, CA: Portola Institute Inc., 1970), quotation from inner cover.

> properly developed and humanely managed, the new communications technologies held within them the power to unleash something truly revolutionary.[37]

The counterculture holographers sought to employ holograms in ways that they hoped would be socially revolutionary, a goal that was promoted by creating new variants of the medium. Artists and artisans of the 1970s, many trained at the San Francisco School of Holography, were responsible for developing new types of hologram that held little intrinsic interest for their first developers, the engineers and scientists funded by classified research. The most important of these technical developments was the 'rainbow' hologram devised by Stephen Benton in 1969 but first valorised and promoted by artist Harriet Casdin-Silver in 1973. While this form of hologram makes important technical compromises that make it unappealing to engineers and metrologists (dispensing with vertical parallax in order to allow it to reconstruct an image from a white-light source, and suffering from a degree of optical distortion), the rainbow hologram opened new possibilities for artists who, for the first time, could generate coloured images. A second key innovation, for artists but not engineers, was the 'multiplex' hologram (or *holographic stereogram*) developed by Lloyd Cross himself, which permitted animated three-dimensional scenes to be played out in front of the observer.

These new emphases in social goals, cultural purposes and technology originating in the counterculture were diametrically opposed to those promoted by the originators of the hologram.

## 5. Reshaping the past

My account contrasts with the rather superficial historical sketches that narrated the development of holography's first fifty years, curiously downplaying the role of military context in its origins and evolution. As discussed here, the influence of

[37] Ross, David A., 'Radical Software redux', http://www.radicalsoftware.org/e/ross.html, accessed 11 Nov. 2004.

wartime and immediate post-war concerns channelled the careers of Europeans such as Dennis Gabor and Adolf Lohmann. Post-war State support of research – especially militarily-oriented research – was important at institutions that developed holography, notably Stanford University, the University of Michigan, the Vavilov Institute and the Massachusetts Institute of Technology. And the countercultural response to this military-industrial-academic alignment yielded new visions of holography during the 1970s.

Uncovering this hidden history has not been straightforward. Those involved in classified research work, such as Emmett Leith and Yuri Denisyuk, were reluctant to breach security when interviewed by the author in 2003-5. The later engineer-entrepreneurs who found careers in commercial holography generally emphasised market forces rather than acknowledging the ample military funding of the 1960s for enabling their achievements. And among the artisans who entered the subject during the 1970s, associations with the counterculture now have a faintly embarrassing connotation. As a result, oral histories have been shaped by an internal rewriting of the histories by the participants themselves. Moreover, the surviving holographers have preserved those mementoes and records that justify their retrospective points of view, thus further shaping past history from a presentist perspective.

This reshaping of the past does not represent a conspiracy or cover-up to deny the importance of the military origins of holography; it is an individualistic response shaped by modern cultural attitudes. By comparing the participants' recollections with contemporary records in archives (including government project reports, university administrative files, lab notebooks, business records and private correspondence) the historical veracity can be improved considerably.[38] From this,

[38] On the historiography of holography, see Johnston, Sean F., 'Reconstructing the history of holography', *Proceedings of the SPIE - The International Society of Optical Engineering* 5005 (2003): 455-64, and, Johnston, Sean F., 'Attributing scientific and technical progress: the case of holography', *History and Technology* 21 (2005): 367-92.

we can gain a rounded perspective on the fascinating but now almost forgotten influences that shaped the early field of holography.