CHAPTER 1

A Historian's View of Holography

Sean F. Johnston

University of Glasgow, Crichton Campus, Dumfries DG1 4ZL, United Kingdom

CONTENTS

BIOGRAPHY

Sean F. Johnston, a historian of science and technology and physicist, is Senior Lecturer in Science Studies at the University of Glasgow. He has written widely on the history of modern optics and the technical professions, notably *Fourier Transform Infrared: A Constantly Evolving Technology*, Simon & Schuster (1991), *A History of Light and Colour Measurement: Science in the Shadows*, Institute of Physics Press (2001) and, most recently, *Holographic Visions: A History of New Science*, Oxford University Press (2006).

1. INTRODUCTION

For holographers immersed in their subject, the history of holography may seldom prompt deep reflection or justification. Research is guided by straightforward scientific questions, and development is impelled by technological and economic goals. This is not to say that holographers are necessarily driven merely by narrowly scientific or utilitarian motives. Optical sciences can have an aesthetic appeal, and holography, in particular, is elegant both theoretically and visually. But for outsiders, often unaware of such dimensions, awkward questions are more likely. Why haven't we got holographic television? Why are holograms so difficult to light properly? And when will holograms be as good as the holographic doctor on *Star Trek: Voyager*?

These questions may irk holographers, who are usually quite justifiably concerned with other matters. But they are not chosen randomly: they are examples of queries particular to different generations and audiences, and they question the origins of the subject and its future.

Historians have their own cluster of uninvited questions, situated somewhere between the technical concerns of practitioners and the more naïve inquiries of the wider public. They, too, may look both backward and forward, trying to understand possible futures in terms of what has come before. Why, for example, has holography evolved in the way that it has? What shaped the directions it took? Can its history tell us anything about the nature of discovery, invention, marketing, or progress?

Just as holography allows observers to see an image with multiple perspectives, exploring its history demands a range of viewpoints. Its past has never been summarized adequately by its practitioners, because the subject has been divided up by scientist–engineers, artists, artisans, and

ISBN: 1-58883-079-9

New Directions in Holography and Speckle
Edited by H. John Caulfield and Chandra S. Vikram
Pages: 1–14

entrepreneurs. Each group assessed the history, success, and future of its subject differently. Hundreds of capsule histories of holography have been written since the 1950s, appearing in newspapers, magazines, conference proceedings, scientific papers, introductions to books, and holographers' folklore. They have been written at distinct times for diverse audiences, and often came to dramatically different conclusions about which ideas, events, players, and products were important. Physicist Paul Kirkpatrick, for example, who explored the field with his Stanford University students during the early 1950s, downplayed the work of the subsequent generation by citing a 200-year genealogy for holography. He was nevertheless acutely aware of the subjectivity of categorizing the field and its history, suggesting that definitions of holography "had better be clearly stabilized before its malleable period passes" [1]. Indeed, physicist George Stroke of the University of Michigan energetically advanced his own version of what he called "the now historical account" to support his priority claims and to influence the awarding of the Nobel Prize to Dennis Gabor alone in 1971 [2]. By contrast, physicist Yuri Denisyuk, at the Vavilov Institute in Leningrad, struggled to communicate the meaning and significance of his own work at home and abroad until it was rehabilitated by developments in the west. And by the early 1970s, yet another perspective was being experienced and told through the eyes of a small counterculture community in San Francisco, an account that has since become part of the oral folklore of the subject [3]. Over the following twenty years, these accounts were swamped by a wave of tales about entrepreneurs, proprietary processes, and business rivalries. And at technical conferences, it has been the longest-lived and best-funded participants whose stories have held sway almost as mythic tales.

This chapter surveys those perspectives to reconstruct a more inclusive and coherent view of holography's history. In doing so, it highlights the attractions of this field for historians and other academics.

2. EARLY JUDGMENTS OF FAILURE

Part of the interest in holography for historians concerns the way it has been perceived by its practitioners. During the first two decades of holography (1947–1966), concepts were clarified but forecasts shifted dramatically. The young subject was shaped in three intellectual environments and became tied to existing concepts, inventions, and metaphors, each of which shaped perceptions of its prospects and defined its criteria of success.

The world *holography* did not come into common usage until 1966, but the terms *hologram* and *holoscope* were coined in 1947 by Dennis Gabor (1900–1979), then a research engineer at British Thomson-Houston in Rugby, England. Gabor, a Hungarian, left Germany when Hitler came to power and invented products at British Thomson-Houston ranging from discharge lamps to techniques for three-dimensional cinema to schemes for frequency compression in communications. In early 1947, he conceived a two-step process for improving the imaging of electron microscopes. In his scheme, he planned to record the physical shadow (*hologram*) of a microscopic object cast by an electron beam, and to then use this recorded fringe pattern in an optical apparatus (which he dubbed a *synthesizer* [sic]) to synthesize or reconstruct a visual image of the object from the diffracted wavefront. The resulting image would be viewed through a single microscope eyepiece [4, 5].

As others pursuing the subject would later discover, Gabor found that he attracted most attention from his peers by demonstrations (by contrast, his scientific papers were rather turgid and difficult for his contemporaries to follow). During early 1948, Gabor brought his apparatus and posters to meetings of microscopists and of the British Association for the Advancement of Science. From the demonstration, and with the patronage of Sir Lawrence Bragg, he garnered the only newspaper report to describe the hologram for the next fifteen years [6].

His two-stage system, which Gabor called a *holoscope*, had some similarities to a two-step imaging concept proposed by the Polish physicist Miecislav Wolfke (1883–1947) in 1920 [7] and developed by Sir Lawrence Bragg (1890–1971) from 1939 [8]. Both had imagined a two-step imaging technique, using x-rays as the first step and visible light as the second. Indeed, the idea of dividing the imaging process into two parts—an optical transformation, followed by a second transformation to form the image—was used as a conceptual convenience by the German microscope designer Ernst Abbe (1840–1905) during the late nineteenth century. Wolfke, who was one of Abbe's doctoral students, recognized that this process could pay dividends if implemented physically, because the image would be magnified by the ratio of wavelengths used in the two steps. Gabor used electron waves rather than x-rays and crucially added the idea of mixing it with a reference wave (namely the undiffracted light passing by the microscopic object) to allow phase, as well as amplitude, to be recorded.

Those earlier techniques had theoretical and practical limitations, but so did Gabor's new method of *wavefront reconstruction*. His collaborators at Associated Electrical Industries (AEI) found that their electron source was unable to generate more than about seven fringes of interference; to do so, an exposure time of at least thirty minutes was needed, during which the source had to be controlled to scrupulous tolerances; and the reconstructed image was overlaid by another conjugate image [9]. Despite their enthusiasm, Gabor [10] and others (notably Paul Kirkpatrick and his students Hussein El-Sum [11, 12] and Albert Baez [13] in California, Gordon Rogers [14–16] in the United Kingdom and, later, Adolf Lohmann [17] in Germany) were unable to find a satisfactory solution to the twin image and other problems.

Gabor's broad background and research interests led him towards a new microscopic imaging technique, but no further. While Gabor recognized that this process should yield a three-dimensional image, he did not imagine it being viewed with two eyes. Instead, he emphasized that the hologram would record a large depth of field, allowing the wavefront microscopist to examine the different planes of the image at leisure. Despite Gabor's experience in physics, electronics, information theory, and stereoscopic cinema, he was screened by the context of his working environment and commercial goals; he was channeled to develop an awkward, if theoretically intriguing, variant of microscopy. But by merging electron microscopy with visible optics, wavefront reconstruction had aspects that appeared retrograde rather than progressive. Instead of the immediacy of seeing an image on a fluorescent screen (as some electron microscopes then produced), the reconstructed image was to be obtained more painstakingly via a half-hour exposure, followed by conventional photographic processing, unintuitive optical transformation, and observation through a conventional microscope eyepiece. For Gabor, his AEI colleagues, and practicing microscopists, these meager practical accomplishments amounted to a failure. Nevertheless, they identified *different* failures: Gabor blamed lack of enthusiasm from his industrial collaborators and microscopic manufacturers; the AEI team held instabilities of the electron apparatus to be responsible; Gordon Rogers and the Californian investigators were stymied by the twin-image problem; Sir Lawrence Bragg criticized Gabor's impractical optical arrangements; Max Born complained that Gabor's concepts and explanations were "a little weird" and "prickled [his] sensibilities"; and, microscopists dismissed what they saw as a hybrid and unfamiliar technique. For the Research Director at AEI, wavefront reconstruction was, by the late 1950s, a white elephant [18, 19].

Just as western investigators were giving up, a related subject developed along very different lines was created at the Vavilov State Optical Institute in Leningrad. Yuri Denisyuk, an engineer researching his *Kandidat* degree (roughly equivalent to the western PhD) from 1958, conceived what he called *wave photography* to record and then replay a wavefront of light [20–22]. Like Gabor, he employed a mercury lamp as his coherent source. Unlike Gabor, he and his colleagues developed thick, high-resolution, and relatively sensitive photographic emulsions to record the wave pattern in depth [23]. Denisyuk's wave photographs could reconstruct the image of a three-dimensional surface, but without the necessity of a focusing lens. His first holograms were of spherical mirrors and reflective rulers.

The technique was different in concept and implementation from Gabor's. It could reconstruct three-dimensional images by reflection from the hologram in white light and had no conspicuous link with either microscopy or information theory. Instead, its more demanding recording conditions made it rather analogous to a nineteenth-century daguerreotype, but with the addition of depth and (potentially) color. Denisyuk portrayed his technique as a superior and generalized form of Lippmann photography for a limited class of objects, or as a color-dependent optical element. But because of his unimaginative portrayal of applications and lack of an influential early mentor, his Soviet contemporaries largely ignored Denisyuk's research.

Thus, two separate lines of research yielded complementary techniques that were poorly received by contemporary optical scientists. The failed subject nevertheless was rehabilitated posthumously; indeed, Gabor was to be awarded the Nobel Prize in Physics for holography in 1971. Subsequent evaluations of this work were recast, converting it from a white elephant into an example of what was then seen frequently as the inevitable progress of science.

This reversal of judgment was triggered by a third line of research undertaken at the Willow Run Laboratories of the University of Michigan, near Ann Arbor. Willow Run was a classified research center on a 150-acre site at the local airport developing, among other things, synthetic aperture radar. From the early 1950s, researchers there investigated optical methods of data analysis and one of them, Emmett Leith, gradually conceived elegant optical schemes for converting the synthetic aperture data recorded on photographic film into a visual image. This two-step process, Leith realized by 1958, was similar to Gabor's wavefront reconstruction.

From 1960, he and his new colleague, Juris Upatnieks, began to repeat Gabor's experiments but informed by the perspectives of additional theory. Merging physical optics with communication theory, Leith and Upatnieks found another method of sidestepping the technical disadvantages of the twin-image problem, and by restricting their work to optics, they avoided the complexities and diversions of microscopy. Impressive results followed from their research: first, the ability to produce clean reconstructed images of line drawings by early 1961 [24, 25]; second, high-quality gray-scale images at the end of 1962 [26]; and finally, with the use of the newly available laser as a coherent light source in late 1963, an astonishing form of three-dimensional imagery in which the reconstructed images exhibited depth and parallax with unprecedented realism [27, 28]. When viewed in the light of Gabor's work, the achievements represented a rapidly rising ladder of accomplishment.

Thus, the work of Gabor, Denisyuk, and Leith-Upatnieks created at least three versions of an intellectual concept and its associated technologies: either an instrument for improved microscopy, a method of recording the complete optical properties of a shallow object on a reflective plate, or a type of three-dimensional, lensless photograph in the form of a transmissive window. These divergent conceptions, arising from different technical and occupational contexts, profoundly shaped the early forecasts of the subject that became holography. Moreover, their respective successes were evaluated differently. Gabor's narrow portrayal of wavefront reconstruction during the 1950s yielded few forecasts beyond improved microscopy. His concept was self-limiting and of interest principally to workers interested in ultra-microscopy and the then-limited field of physical optics. Denisyuk's self-assessment was similarly derided or ignored. By contrast, the Leith-Upatnieks conception excited great interest far beyond the domain of physicists and engineers.

3. HOLOGRAPHY AS ADVANCED PHOTOGRAPHY

Leith and Upatnieks spent the following two years scaling up their research with colleagues at Willow Run, and publicizing and demonstrating their new technique, gradually becoming known as *holography*, at a series of engineering conferences. For wider audiences, the apparent conjuring act was most easily understood as an advanced form of photography.

This identification was a source of the new judgments about holography: when the imaging achievements of the 1960s were linked with those of the late 1830s, a soaring rise was obvious to all. But the subject strained to support this perceived link with the photograph. The Leith-Upatnieks hologram was a kind of transparency, but the image was observed by looking *through* the hologram as through a window. Its featureless surface was described as storing the image for later reconstitution. A contact copy of a hologram yielded not a negative image, but another positive. And unlike a photograph, the hologram could recreate a view of the entire image from any part; the pieces of a broken hologram still worked. The technique was also restrictive: only small laboratory scenes could be recorded. And the transmission hologram was tied to the laser as a light source, not just for its initial recording but also for subsequent reconstruction.

The unfamiliar attributes of this "window with a memory" were difficult to reconcile with concepts of photography, but despite the imperfect correspondence, photography was to be a convenient guide to understanding the new medium and in forecasting its future development. Like early daguerreotypes, holograms took several minutes to record and demanded great skill from their specialist operators; like daguerreotypes, holograms initially were expensive, precious, and rare. And, like early photography, holography was widely expected to develop technically, becoming cheaper, more capable, and widespread. In short, the commercial future looked certain [29].

4. HOLOGRAPHY AS A PARADIGM OF PROGRESS

For most American observers, the Leith-Upatnieks technique was framed in terms of a potential success story, especially when linked with the early work of Gabor or, even more convincingly, with early photography. These historic associations acted as a lever for the slope of progress: with them, the accomplishments of the 1960s were cast upwards and made to represent an exponential improvement that seemed bound to continue. Forecasts were tied to genesis myths: the predictions of the future were crucially dependent on particular claims about origins.

Predictions made between 1964 and 1971—bracketed by the announcement of the Leith-Upatnieks hologram and Gabor's Nobel Prize—were uniformly expansionist, making optimistic extrapolations based on laboratory demonstrations or anticipated applications. Gabor himself predicted incautiously in 1969 that by 1976 his brainchild would become a billion-dollar industry [30]. Edwin H. Land, Director of the Polaroid Corporation, provided a typical prophecy when he declared around the same time that "*hologram* will be a household word in 25 years" [31] (in fact, the word became ubiquitous sooner, but in the context of science fiction rather than consumer products).

An important source of these optimistic forecasts was the advocacy of Kip Siegel, Director of the Conductron Corporation in Ann Arbor. Conductron, founded in 1960, employed several former Willow Run engineers to supply optical processors and synthetic aperture radar for government contracts, and from 1965 sought to commercialize holography by identifying market niches. Siegel promoted holography to investors by drawing upon their assumptions that the technology was ripe with latent potential for inevitable expansion. Conductron's approach was to develop proof-of-concept demonstrations, an extension of methods pursued in military research contracts. His engineers produced ever-larger holograms for customers, such as nearby General Motors; developed a pulsed ruby laser in 1967 that could record human subjects; created short, animated holographic movies to impress would-be investors in the company; and produced the first mass production of holograms. Underlying this approach was the expectation of an inevitable technical payoff.

Siegel proselytized a message seeded with a progressive philosophy, to which his military and commercial sponsors were receptive. Yet the success of Conductron's holography development was ambivalent. Its engineers worked to realize Siegel's expectations of progress, advancing the technical possibilities such as producing successively larger holograms for trade show displays. While such holograms attracted interest and exemplified the technical progress being made in image reproduction, their display requirements (such as the two or three carefully aligned and power-hungry lasers necessary for color holograms) made them too unwieldy to be sold or even displayed outside the lab.

Similarly, the development of pulsed-laser capabilities illustrated clear technical improvement in a limited domain over only a short period, but was company-funded and commercially sterile. Conductron engineers recognized that producing practical holographic movies would require a high-powered pulsed laser to record moving objects—such as people—before they could move enough to smear the interference fringes on the photosensitive plate, and that such a laser for recording outdoor scenes would certainly have dangerous and unattainable power requirements (this disparity between the technical requirements and plausibly achievable "progress" is reminiscent of the later Strategic Defense Initiative promoted by physicist Edward Teller [Dennis Gabor's contemporary and fellow Hungarian], which also relied on high-powered lasers). Nevertheless, Conductron developed a pulsed ruby laser that produced a beam sufficiently intense to record a human portrait in a darkened room. When further technical improvement proved impossible, the Conductron marketing staff sought to redefine their goals, turning from holographic movies to static three-dimensional human scenes for advertising [32].

Progress was also touted in terms of production range and capacity. Between 1965 and 1970, the firm's promiscuous origination of over a thousand custom holograms for clients ranging from pharmaceutical manufacturers to artists culminated in the unprecedented achievement of manufacturing half a million holograms for the 1967 *Science Year* book . Nevertheless, this too suggested uncertain AQ1
commercial success: production costs were covered, and the publication proved to be the best-selling edition of the series, but no orders of comparable size followed.

Thus, the notion of progress was problematic from the outset: displays became more impressive, but the necessary equipment multiplied in cost, complexity, and unreliability.

And unlike other commercial ventures, which commonly have a discouraging and resource-draining development phase, Conductron's holography operations were never satisfactorily "black boxed", that is, reduced to a well-established fact or unproblematic product [33].

Like a series of holography companies that followed it, Conductron was the messenger of a particular view of progress. Its holograms were an embodiment of all that was new and valued in that technologically optimistic decade, melding the laser, high science, and awe-inspiring imagery into an example of a seemingly inevitable technical advance. Its engineers were habituated to exploring applications creatively in a classified context and with relatively abundant funding and were imbued with confidence in the very notion of inexorable progress. They arguably were less sensitive to commercial pressures than were typical workers in industry; however, it was because they envisaged holography as a dramatic and inevitable extension of photography. Conductron consequently sought display applications that highlighted its three-dimensionality and visual impact. Less convincingly, its engineers forecast and pursued the extension of holography to color imagery, movies, and television based on the technical trajectories of those earlier imaging media. And most misleadingly, again using the analogy of early photography, they predicted a rising public appeal and inevitably growing market like its antecedents. This divergence between marketplace reality and commercial claims is not unique, of course: it was a feature in other new technological fields such as nuclear power during the 1950s, biotechnology from the 1980s, and nanotechnology from the 1990s [34].

In a more restrained fashion, other firms also cited practical indicators of progress for the new science. From the late 1960s, for instance, holographic interferometry (and especially *holographic nondestructive testing* or HNDT) became popular with metrologists and mechanical engineers and found a market niche. The commercial holographic tire-tester, developed by Ann Arbor's GC-Optronics, for example, allowed the lamination of airplane tires to be verified rapidly. For this application, the criteria of success were economic (lower costs), technical (better testing reliability), and social (improved customer safety).

But the often-vain expectation of steady technical progress led a number of large firms to withdraw quietly from the field by the early 1970s. CBS Laboratories, for instance, which had long employed Dennis Gabor as a consultant, generated patents but devised no promising holographic products. RCA developed a prototype consumer video playback system (Selectavision Holotape) in 1969, but cancelled the project when the firm was in financial difficulties and facing competition from more versatile magnetic recording technologies. McDonnell Douglas, which had bought Conductron and moved its holography operation to Missouri, closed its pulsed holography operation in 1973 owing to lukewarm interest from the advertising industry and corporate customers. IBM's early enthusiasm for holographic computer memories did not culminate in products. And Polaroid Corporation, while developing recording techniques and new photosensitive media during the 1970s, did not market them aggressively.

Thus, the first flush of scientific and technical confidence in holography's progress was eroded within a decade. And the enthusiasms of technologists did not necessarily translate to those of wider culture. Marketing holograms proved unexpectedly difficult, and there was increasing disjunction between technical forecasts and economic reality. But new constituencies of holographers defined new goals.

5. THE CHANGING FACE OF HOLOGRAPHERS

The first holographers—Gabor, Denisyuk, Leith, and their colleagues—were trained in physics or engineering and initially published their work in optics or electronics journals. By 1968, though, publicity and displays had drawn new would-be users to the subject [35]. Two new groups were to appropriate holography for new goals.

A handful of artists, supported by scientists at first, began to take up holography. Inspired by the art and technology movement that was then exploring videotape, architecture, and other influences, they sought to make fine-art holograms. For artists, success in holography was evaluated according to distinct criteria. The medium had to have adequate technical versatility to support aesthetic expression, and the new art form required the acceptance of art critics and a receptive public. While this was relatively free of progressive underpinnings, these criteria did embody the assumption that the capabilities and audience for the medium would inevitably expand. Their definition of progress was a combination of growing audiences and prices for fine-art holograms, alongside the development of new techniques of production, especially cost-effective or simplified methods. The notion of a "young but maturing art" was expressed frequently [36].

A second new grouping of holographers sprang up in direct opposition to what they saw as the military and corporate focus of modern technology. This loose group of counterculture holographers, most having either fine-art or technical backgrounds, sprang up in San Francisco around Lloyd Cross, who worked at Willow Run and for Kip Siegel during the 1960s. During the early 1960s, they formed the San Francisco School of Holography, an organizational and teaching format quickly copied in New York and other centers, to make holography an expressive medium for anyone. Their countercultural ideals, focused initially on appropriate technologies and metaphysical meanings for the subject, evolved by the early 1980s as a skills-based collective for cottage industry. It is noteworthy that the community of artisans, like fine-art holographers, often supported this implicit assumption of technical progress and consequent mass popularity even while embracing countercultural themes.

6. ASSESSING PROGRESS

For each of these communities of holographers, success was defined in terms of *expansion*, which amounted to anticipation of continual progressive increase. And for all three communities—scientists, artists, and artisans—stagnant conditions, measured in terms of income generation, technical abilities, and acceptance by critics, consumers, students, or the wider public, equated to failure for the subject.

By the 1980s, despite its exposure to hundreds of thousands of viewers through public exhibitions of holograms and the growing ubiquity of mass-produced holograms, the subject could not be characterized reliably by these criteria and appeared different to each constituency. The impalpable state of progress can be illustrated by bibliometric indicators: by the mid 1990s, while the annual publication rates of papers and patents were rising, those of books and theses were falling, and the number of scientific conferences and hologram art exhibitions had diminished to half their value of a decade earlier [37]. For artists and artisans, the field appeared to be declining; for scientists, it had periodic ups and downs; but for inventors and investors, it continued to look promising. Economic, rather than population, indicators consequently became a widely accepted mark of success of the medium. For different communities then, holography was a subject that evinced obvious success, remained latent with potential, or had outlived its promise.

Holographers were vocal in assessing the progress of holography. Practitioners are often the principal narrators of the evolution of a young technical subject, and the first judges of its significance and potential, so historians' evaluations can be reliant on contemporary judgments. The validity of technological progressivism has eroded over recent decades within communities of technologists and scientists, but it has continued to inform judgments of success. Historians of science and technology can inadvertently sustain such viewpoints by omission, overlooking subjects that do not demonstrate commonly recognized indicators of achievement, although there have been some recent studies of so-called failed technologies [38–40]. Such criteria are usually taken to include the intellectual, cultural, and economic impact of new sciences and technologies. Other sociological indicators may include the emergence of a disciplinary presence in academic curricula, a professional identity, and the growth of occupations related to the new subject. Yet the absence of some of these characteristics excludes a wide range of subjects in science and technology from consideration, and indeed recent studies by historians and sociologists argue that such fields represent a distinct class that they dub *research-technologies* [41]. These unstable subjects do not fit recent sociological explanations of consensus. They may not, for example, show convincing closure of technical and intellectual debates, in the way discussed by sociologists Pinch and Bijker [42], who have analyzed the social factors in the closure of debates surrounding technological options in bicycle design, or by historian Douglas's account of early radio [43] (in other words, arguments eventually get settled, explanations become universal, and designs come to be seen as optimal). Holography differs from such cases because it deals with a technology that has not achieved a consensual evaluation by any user group for more than a brief period.

The case of holography demonstrates how technical groups can assess success and failure differently, and thereby influence the fate of the technology and its subsequent historical evaluation. But a more sensitive approach than studying these two alternate endpoints is to study attributions of progress for a subject-in-the-making. During the evolution and lifetime of a technology, outright success and failure are seldom judged; instead, practitioners and adopters evaluate progress so as to apply corrective measures, make decisions about adoption, or revise forecasts. Only in retrospect does the subject acquire the totalizing label "success" or "failure." By observing how progress is evaluated group-by-group and case-by-case, we can gain a clearer understanding of their effects on the technological trajectory and ultimate judgment of a subject, and how they relate to historians' assessments. Such analysis can reveal the overgeneralizations and unbalanced perspectives that promote overconfidence in technological determinism.

Holography is a convenient case for a study of this kind, because it has attracted several technical constituencies and yet has had elusive consensus. While in some respects a typical post-Second World War technical subject, holography has been unusually wide-ranging in the applications and social groups that it encompassed. The subject found relatively stable niches as a scientific specialty, technical solution, and art form, but attracted ambivalent assessments of progress. Holography has been both vaunted and criticized based on the contrasting criteria of its unusually broad range of technical communities. As a result, it is a rich historical case for exploring attributions of progress, success, and failure.

How do the backgrounds of different communities and changing scientific, economic, and political environments influence the reception of a new technology? Context is crucial. The new science of holography was situated within the peculiar late twentieth century environment that melded the military, commercial, and popular engagement with scientific and technological subjects. These contexts generated competing criteria by which they assessed their products and their progress [44].

The contrasting judgment of emerging constituencies can be illustrated by the goals of holographic imaging. The occupational specialists of holography variously identified the strengths and weaknesses of holographic technology. They argued that a collection of limitations surrounding the hologram prevented the expansion of the technology of holography in wider culture. This was a two-way process: their mutually incompatible criteria encouraged the holographic communities to differentiate further.

The perspectives of these distinct communities identified contrasting limitations for the medium. The first to be noted were problems with the laser itself. Holograms illuminated by lasers were obscured by laser speckle, making the reconstructed image and, indeed, any surface illuminated by the laser, shimmer and sparkle with a graininess that depended critically on the position of the observer's eyes. This artifact was a complaint of scientists and engineers more than of aesthetic holographers: speckle was a particular problem when photographing holograms, an activity common in scientific and engineering studies but relatively unimportant for casual viewers.

On the other hand, the cost of the laser was a crucial constraint for artists and advertisers but of relatively little importance to well-funded scientists. Lasers were also unfamiliar and intimidating for nonscientists, and their use was curtailed severely with the introduction in the early 1970s of safety legislation concerning eye exposure. But lasers were also relatively dim light sources for reconstructing the holographic image—adequate to illuminate a single hologram well in a normally lit room, but not in a daylight-flooded shop window. If any other form of light were used to reconstruct a hologram, the image would be unacceptably blurred. Neither of these restrictions was a particular problem for scientific applications such as holographic interferometry, but judged to be a severe limitation for public displays.

A third characteristic constrained holography as a medium for portraits. The very monochromaticity of laser light provided eerily unworldly images akin to the street illumination from sodium lamps or the orthochromatic images of early photographic and cinematographic films. The contrast and tonal gradations of reconstructed images appeared unfamiliar and were inferior to the panchromatic black-and-white films that had been used universally since the second World War.

This effect was exacerbated in the portraits made with pulsed ruby lasers. Because human skin is slightly transparent to the deep-red color of a ruby laser, portraits made subjects look waxy-skinned, blotchy, and disturbingly morbid. Holograms produced with pulsed lasers, acting like a fast-flash camera, captured unsettlingly frozen facial expressions of their subjects who had been sitting in near darkness, often accentuating the unfamiliarity by showing the unusually wide irises of the dark-adapted eye. Artists who adopted pulsed lasers most successfully employed them for figure studies rather than facial depictions. For photographers then, holographic portraiture represented problems not progress.

In sum, these limitations restricted holography to a narrow class of subjects and applications, paradoxically in opposition to its highly realistic perspective. The problems and putative solutions were ranked differently by different communities.

The most pressing problem for aesthetic and commercial users (but irrelevant for scientists) was the need for a laser to display the hologram. Denisyuk's holograms of the early 1960s offered a solution by providing a clear green image when viewed in sunlight or room lighting. But creating such holograms demanded extremely high-resolution photographic emulsions and very stable conditions during the exposure. They had a low uptake in the West because suitable emulsions and chemistry were not readily available, and because artists perceived them to offer limited options for creativity.

A solution for some audiences was the image plane hologram, which produced little color smearing of reconstructed images for points near the plate, so a white light source was adequate to view holograms of shallow objects. A secondary advantage was that such images were even more striking than conventional holograms: the image appeared to pass through the hologram plate. This appealing attribute became ubiquitous in commercial and art holograms by the mid 1970s but was of little interest to the scientific community.

During the early 1970s, the rainbow hologram also became widespread. With it, a sharp image could be viewed in white light, although cast in a spectrum of colors that shifted with the viewing position. Its developer, Stephen Benton, a well-known intermediary between scientific and artistic communities, developed variants when he joined the new MIT Media Lab. The lab united a collection of enthusiastic engineers and scientists and sought to transform culture via new media technologies, aiming, as one breathless account put it, to invent the future [45].

Rainbow holograms importantly reduced the cost and complexity of display, but had an uneven popularity that further divided advocates. East Coast American holographers, close to Benton's Massachusetts lab, adopted rainbow holograms more enthusiastically than did their West Coast and European counterparts. And artists championed the technique, discovering that, by overlaying several exposures, a single hologram could display multicolored images. But rainbow holography was rejected by Soviet practitioners, who saw the technique as complex and poorer in quality than their own reflection holograms, and by most American scientists, who were concerned with the accurate recording and metrological analysis of three-dimensional objects or transitory events. Benton's later variants, such as the *ultragram* and *edge-lit* rainbow, were little adopted even for display purposes.

From the 1980s, embossed holograms provided new audiences and opportunities for technical judgments and forecasts. Manufactured by the millions on metal foil, they became ubiquitous in packaging, graphic arts, and security applications. While this brought holograms to a much wider audience, it generated dramatically divergent judgments. Unlike the previous varieties of holograms, this new type generated not just indifference from different communities, but outright animosity.

Embossed holograms were inexpensive, reducing the cost of copies by a hundredfold. They could be mass-produced reliably by using a number of proprietary techniques. And they were chemically and mechanically stable, unlike most previous hologram materials that were susceptible to breakage, humidity, or aging. Together, these technical advantages promoted the widespread application of embossed holograms.

On the other hand, connoisseurs of imaging—the self-styled display holographers made up of artists and artisans—soon derided embossed holograms. Their flexibility, particularly on magazine covers, caused color shifts and image distortion. And because the holograms were usually viewed in uncontrolled lighting, images could appear fuzzy or dim. In response to these limitations, their producers progressively simplified the imagery to incorporate shallow, eye-catching patterns, a product that some in the industry dubbed contemptuously "shiny shit."

By moving toward less ambitious images, embossed holograms evolved to minimize their perceived weaknesses and to exploit new markets. While applications such as magazine illustrations declined, others expanded to suit new industries and adopters. Visual appeal was redefined. Their image characteristics made embossed holograms particularly suitable for attention-grabbing product packaging (a profitable and growing industry from the early 1990s) and for security applications, where any defect in the complex pattern could indicate tampering or counterfeiting. From the introduction of credit card holograms in 1983, the hologram industry was dominated by packaging and security applications and represented by a periodical (*Holography News*, published by Reconnaissance International from 1987), annual conferences (Holopack-Holoprint, from 1989), and a trade body (the International Hologram Manufacturers' Organization, 1992) seeking to monitor and regulate an industry growing most rapidly in the Far East.

There was an irony in this market success: this technical mutation arguably amounted to a reversal of the original aims of the medium. Yet consensus about success could not be defined in utilitarian terms. Embossed holograms promoted low-cost mass production but had relatively poor image quality; they brought three-dimensional imagery to vastly increased audiences, but simultaneously reduced the sublime characteristics of depth, parallax, and image clarity. Security applications exploited the complex color shifts and angle-dependence of embossed holograms, making the forgery of credit cards and bank notes more difficult. But for imaging purposes, these characteristics were deemed to be a serious defect. Fine-art holograms declined in popularity, with artists complaining that embossed holograms irreparably devalued the aesthetic attraction of the medium. This expansion of holography into the mass market was thus judged by its initial supporters to be a failure, because it had deviated from their forecast trajectory.

In this transmutation of meaning, the hologram itself became harder to identify. Embossed versions of silver-halide display holograms shaded by imperceptible steps into grating-pixel *kinegrams* for passports. So, too, did holographers, transforming from solitary shrouded workers in quiet labs to computer graphics technicians and press operators. The economics of embossed holograms did not improve the professional situation of holographers: embossing processes were taken over by commercial printing companies using fairly conventional equipment and relied on holographers only for the production of the original master hologram. Further developments by firms such as Dai Nippon threaten to embody holographers' expertise in automated machines.

The evolving techniques for producing bright, white-light holograms thus both liberated the growing field of display holography in the 1970s for commercial use and constrained its acceptance in the 1980s, particularly for artists. The tribulations of display holographers were not faced by most scientific and engineering users, who continued to employ laser-viewable holograms; nor were they recognized by marketers of packaging and anti-counterfeiting holograms. Thus, the applications of holograms supported the growing segregation of practitioners and conflicting definitions of success.

Despite the discordant assessments of display holography, expectations of progress remained strong after holography's first active decade—extending from 1965 to 1974—when uniformly expansionist predictions made unrealistically optimistic extrapolations based on laboratory demonstrations or even speculative applications [46–49]. Indeed, some forecasts, oft rejuvenated, seemed impervious to attributions of failure despite the continued lack of demonstrable viability. The most tenacious *technical* forecast concerned holographic memories for graphic or digital storage. Popular forecasts, on the other hand, ranged from holographic television during the 1970s to holographic computer-generated personalities, as explored by science fiction from the 1980s.

Nevertheless, holography was also criticized for having failed to expand enthusiasm, garner audiences, and develop markets—a failure, in effect, to conform to wider expectations of technological progressivism. Artists responded with dismay, for instance, to negative reviews of *Holography '75* in New York, which curtailed their expectations of aesthetic acceptance and growing markets. Both critics and artists (to their chagrin) portrayed holography as immature and in a state of early aesthetic and technical development; both, indeed, were imbued with a similar definition of progress.

In order to sustain continued confidence, predictions mutated. History-in-the-making demands repeated re-evaluations and changes of course. Dennis Gabor's 1971 Nobel Prize for holography provided a convenient perspective from which to evaluate the emerging subject's past and future [50, 51]. So, too, did the mid-1970s (the end of the "first decade"), the mid 1980s (the end of the "second decade"), and the 1990s and onward, when early workers in the subject began to reflect on their careers and their subject's achievements [52–56]. Although these accounts varied in their predictions, all cast the development of their field as an historic narrative linked with latent or manifest progress [57–59]. This perspective of imminent growth suffused newspaper and popular magazine accounts even more pervasively [60, 61].

When, after one decade, two decades, or a quarter century, material achievements were not obvious to all, the original commentators and others—notably Stephen Benton, who became the most prominent conference organizer and holography pundit—recast the development of their field as an historic narrative either still linked with progress or portrayed simplistically as a classic tale of market failure [62, 63]. When compared to its optimistic forecasts, the subject seemed periodically to pause or stumble, if not decline.

So progressivist accounts of holography coexisted with attributions of its failed potential. Yet none of these later depictions dominated public consciousness of holography. Instead, understandings became shaped by fictional portrayals. Popular anticipation, supported by faith in progress, threatened to outstrip reality. This splitting of real and imagined futures, evident in the earlier commercial forecasts as well as later science fictional accounts, is a theme common to many new technologies. It has parallels with the account that Colin Milburn has given of nanotechnology, for instance. Milburn argues that popular and professional writing about nanotechnology amounts to a "teleological narrative" that transforms a dream into something that is inevitable. He suggests that promotion of the subject has transgressed a line between "speculative science" (an extrapolation of current scientific thinking, describing what could be) and "fictional science" (an account of what, inevitably, will be, in some world to come) [64]. According to this view, Kip Siegel's forecasts could be characterized as fictional science that influenced science fiction writers a decade later. Such incredible extrapolations may not require the disorienting qualities of the hologram, though. The near-utopian predictions for holography, promoted by its fantastic early commercial claims, have been made of other, more mundane, technologies [65].

In any case, such fictional diversions increased expectations and adversely affected the cottage industries of holography that appeared during the 1980s. The small firms selling holograms for home viewing, which had sprung up in large cities after major exhibitions, did not thrive. Small pioneering commercial galleries, such as the Holos Gallery in San Francisco, gradually discovered that sales of holograms could sustain them only if their businesses were transformed into wholesaling operations for distributing holographic trinkets to museums of science and technology. The sale of holographic art, always marginal, declined as holographic kitsch in the form of embossed foils for magazine covers and children's stickers began to flood the market from the mid 1980s. As noted above, it is significant that artisanal and artistic holographers identified this trajectory as nonprogressive and hence an indicator of failure. They commonly characterized the altered focus of public interest as a descent similar to the history of earlier three-dimensional media, transforming them from a sublime technological experience to mere children's products having lower intrinsic value. The criteria of success become more abstract: they judged the *type* of audience to be more important than its size.

The limited public acceptance of commercial holograms meant that real-world holographers continued to struggle for occupational status and acceptance of their products. The subject, its communities, and their aspirations of progress were closely interlinked. The technical groups associated with holography proved unstable, partly because public engagement and employment were themselves uncertain. Holography did not develop applications that generated a stable occupation supported by university-taught courses. The growth of long-lived occupations and accredited teaching programs, usually deemed crucial for the consolidation of a new profession and a new discipline, could not be sustained by the applications of holography. Instead, the subject spawned several marginal constituencies, along with distinct forecasts and criteria of success. Even the best supported of these, the broad field of optical engineering and scientific holography, has found its military and corporate funding difficult to sustain after the Cold War. Artists and artisans found their exhibitions and income reduced by the expansion of embossed holograms and changing public expectations. Colleagues in other fields consequently interpreted the relative social invisibility of holographers as a failure of the subject.

During the late 1980s, when holography was at a peak of visibility, practicing display holographers comprised an active community of about a thousand individuals ranging from scientists to artisans, artists, and entrepreneurs. The New York Museum of Holography (MoH), founded in 1976 to serve not just the disparate subcultures of holography but also the general public, discovered that holographers' sense of community was ephemeral and inward looking. As learned by the schools and cottage industry that appeared during the 1970s and early 1980s, the Museum found that the general public absorbed the ideas and enthusiasms of holographers with difficulty. In response, these budding organizations mounted education campaigns that sapped more traditional profit-making activities. But these oft-repeated initiatives appear to have had only a local and transient impact. While the early 1970s witnessed sustained growth in the constituencies of holography, signs of decline in institutional support of display holography became apparent during the 1990s. The MoH closed in 1992, and its holdings were auctioned and transferred to the MIT Museum a year later; the Museum für Holographie und Neue visuelle Medien in Pulheim, Germany, founded in late 1979, closed in 1994, as did Le Musée de l'Holographie in Paris, founded in 1980; The Holography Unit of the Royal College of Art, an important source of postgraduate fine-art holographers, closed in 1994; the Canada Council ceased funding for fine-art holography in 1995; and, the final Gordon Research Conference of scientist–holographers, initiated in 1972, was held in 1997 [66].

7. HOLOGRAPHY FOR MUSEUM CURATORS

How, then, can the historical trajectory of holography be explained? There are competing accounts: historians sometimes disagree with museum curators, who may disagree with practicing holographers. The subject came to be represented in historical terms as early as 1971, when Dennis Gabor won the Nobel Prize for Physics. Historical accounts were essential to pursue early priority claims and to resolve patent disputes. Subsequent accounts were less personally directed, but promoted the prevailing expectations of technological progress and the expansion of scientific knowledge. As late as the 2000s, however, many practitioners resisted the historicity of their subject, perhaps seeing this as an unfavorable way of judging its trajectory alongside its prognostications, or of relegating it to the past. It is equally difficult for those still active in the field to recognize their activities in a historical sense.

But, of course, histories do inevitably get constructed, often without the direct intervention of the participants and frequently in a simplified form that serves particular agendas. Direct interaction of the historian with those practitioners is ambivalent: on the one hand, holographers provide direct (if occasionally conflicting) personal accounts and interpretations of episodes; on the other, they may resent the interference of an outsider seeking to explain events in ways that may not actively support their interpretations or promote the subject as they would themselves. The historian's account may conflict with others that inevitably suffer from selective recollection and reshaping and rehearsing of events to satisfy simplified chronologies and accounts. The creation stories that have circulated in popular accounts of holography often deviate dramatically from the account given in this book.

The role of artifacts can be significant in embodying or reifying a sense of history. Hologram exhibitions have been used frequently to make the evolution of holography tangible. Nevertheless, the desire to locate missing links can misrepresent, too, as Emmett Leith reflected concerning the preservation of early holograms in a 2003 interview with the author:

> People ask, "well, what was your first hologram, which is the first hologram?" And museums around the country and private collections and so on, people have enough of the 'very first hologram' around [like pieces of the real cross during the Middle Ages, when] you could find, in crypts and grottos, enough pieces of the real cross to start a lumber yard. And some of these holograms that people claim to be the original might be the thousandth.

Attributing a relic-like identity to holograms deemed to be historically important began during the late 1970s, when a historical perspective was becoming established. The flurry of large public exhibitions and retrospectives during that period sought to chronicle a clear history of the young field. The MoH in New York, which organized some of the first large exhibitions, became, for a time, the repository for these significant objects. Religious parallels can be suggested: the identification of relics (carefully transported from one temporary place of veneration to another)—indeed, tales about transporting important holograms to exhibitions are recounted that assume the dimensions of pilgrimage journeys to shrines in Chaucer's *Canterbury Tales*; the multiplication of holographic relics as Leith describes, and their rapid escalation in value; their display in carefully oriented reliquaries; their home in a dark and respected sanctuary.

The analogy to the cult of relics can be taken further, with a handful of individuals—those associated with the production of the holograms—identified in nearly saint-like terms. Thus, for a constant stream of conference delegates, to be photographed with Emmett Leith or Yuri Denisyuk was akin to receiving special grace, anchoring the photographee in history and implicitly validating their own work. This concerns more than mere celebrity: their acolytes express their admiration with anecdotes (parables?) about good deeds and character (modesty and honesty most frequently) and their charismatic influence. The elaboration of these analogies represents a rich oral folklore for holography. But even if the experience of viewing holograms can be evocative of the sublime, the analogy of the hologram as relic-cult is imperfect: few observers suggest that holograms, and their creators, are imbued with powers beyond their ability to evoke a connection with beauty, meditation, or perhaps holism.

Such musings provoke the question of the purpose and future of historical collections. Museums and galleries actively construct popular history. With the perception of holograms as historical objects, and a material culture to be preserved, a relationship grew between holograms, museum curators, and their representation of history (material culture as an intellectual concept owes its origins to anthropology and archaeology, which, from the late nineteenth century, drew object lessons from ethnographic studies of artifacts; collections of illustrative objects go back, in turn, to the 1851 Great Exhibition in London, which sought specifically to demonstrate Victorian industrial progress, and still earlier to eighteenth century *cabinets of curiosities*, intended to reveal the hidden or unusual aspects of the natural world to educated audiences).

However, the uneven preservation of the documentary and material culture of holography illustrates the peripheral status of the field in wider culture.

The papers of Dennis Gabor were collected and archived by Imperial College largely because of the status he achieved late in life with the award of his Nobel Prize; Gordon Rogers donated his own career files to the Science Museum. The papers of other early practitioners, such as Hussein El-Sum, have not been preserved. Similarly, a survey of the holdings in Ann Arbor, the crucible of development of the subject academically, commercially, and artistically during the 1960s, shows that there are historically important documents, equipment, and holograms scattered around the small city, but no historical collections or exhibits focusing on them. The Bentley Historical Library in Ann Arbor holds some of the administrative records of Willow Run, for example, but does not identify holography as a particular collecting category, nor does it presently hold much archival material specifically on the subject. Most documents remain in the hands of individuals—participants as students, entrepreneurs, classified research workers, or commercial engineers—still living in the area.

Nor have firms and institutions made more than a casual attempt to preserve their past. Carl Aleksoff, for instance, at Willow Run Labs as a student and then with its successors ERIM, ERIM International, Veridian, and General Dynamics, recalled to the author in 2003 that optical processing equipment reaching the end of its working life was revealed to visitors, but ultimately neglected:

> For a number of years these things were displayed in the lobby—but it's all been thrown away. You can only do it for so long. For a bottom line profit motive, you've got to account for how much area you have—so many square feet—what are you doing with it? How productive is it?

Despite the relatively long-term stability of organizations funded principally by military contracts, WRL/ERIM/Veridian/General Dynamics suffered from the demands of secrecy, which are incompatible with the preservation of open history. This is equally true of the more commercially oriented Ann Arbor firms, such as the Conductron Corporation, KMS Industries, and GC-Optronics. The companies were simultaneously constrained by classified contracts and by the desire to control commercially useful proprietary knowledge, on the one hand, and the desire to vaunt technologies that they hoped would become major income-generating streams, on the other.

This patchy preservation is not restricted merely to commercial firms and classified-research organizations. From 1993, the MIT Museum in Cambridge, Massachusetts, held the largest collection of publicly accessible holograms in the world. Founded in 1971, the MIT Museum shares a former radio factory situated on the northern edge of the MIT campus with a number of other MIT tenants and preserves, displays, and collects artifacts in five disparate subject domains significant for the institution's history. The holography collection includes some 1500 holograms acquired after the demise of the MoH, and covers a period from the early 1960s to the late 1980s. Only a few dozen holograms, at most, can be displayed owing to space restrictions, and the MIT Museum attracts somewhat fewer visitors than did the MoH. When the holography collection was acquired, the museum opened an exhibition of holograms in the main gallery in 1994, and attendance figures rose dramatically. Nevertheless, the gallery space was later subdivided, with the hologram display reduced and moved behind a more popular exhibit on the rising subject of artificial intelligence.

The collection is disproportionately distributed, with more holograms from the mid 1970s to 1980s when the MoH was most active, and few after the mid 1980s when the MoH encountered more serious financial and administrative difficulties. The associated archives of the MoH held at the MIT Museum provide an excellent snapshot of holography's most fertile and expansive period as a cottage industry and would-be art form, 1975–1985. This leaves, though, a substantial period little represented in archival collections. Despite the commitment to preserve and make these resources available, the MIT Museum has not had the luxury of a permanent curator of holography, controlled-environment storage conditions for the collection, nor an explicit collection policy that enabled it to continue to acquire representative examples of holograms or documentary records. This is perhaps understandable for a university museum that has a remit primarily to document the institution itself. However, MIT has been a major participant in holographic research through the Media Lab, so the holography collection arguably conforms to the Mission Statement, aiming to "document, interpret and communicate, to a diverse audience, the activities and achievements of the Massachusetts Institute of Technology and the worldwide impact of its innovation, particularly in the field of science and technology" [67]. Interestingly, relatively few of the Media Lab holograms were displayed at the museum during Stephen Benton's life, although there was a limited exchange of examples serving as demonstration items for courses. A collecting policy was drafted in 2001, but limited funding and curatorial resources restricted new acquisitions [68].

The MIT Museum has attempted consciously to make best use of its holography collection while serving other requirements. Its limited resources are not unusual, however. Larger national museums—the Smithsonian Museum in Washington, the Science Museum and Victoria and Albert Museum in London, the National Museum of Photography in Bradford, United Kingdom, and the Deutsches Museum in Munich, for example—each of which has mounted holographic displays, commissioned or acquired holograms—have not established collecting policies to preserve the ephemeral material culture of holography. (Chris Titterington, while Assistant Curator of photographs at the Victoria and Albert Museum in London from the 1980s until 1995, established a hologram collection policy, but this did not outlive his tenure). This too, may be understandable, if one assumes the remit of technology or cultural museums to be the recording and valorizing of technologies perceived to be successful, relevant, or influential. Historians increasingly question such asymmetrical representation of the past, however. It biases the historical record to suggest that progress is natural and straightforward, and that subjects declining in economic or popular impact are unworthy of attention. As discussed above, a balanced treatment of perceived successes and failures is necessary not only to understand past events, but also to learn from them. Yet museums, defined by their sponsors, remits, and audiences, are often compelled to present stories of progress. By being pigeonholed in this way, the history of holography is pared down to an unfaithful representation. As a result, there has also been an understandable dissonance between the stories told for different audiences.

8. HOLOGRAPHY AS AN EMERGING SCIENCE

Just as I have identified the emergence of broad types of holographer having distinct visions of their field, so too there are different outsiders' perspectives. The range of such approaches has multiplied over the past century as historians, philosophers, social theorists, and scientists discarded simpler but unsatisfactory explanations of how new subjects evolve. Until recent decades, in fact, two mutually supporting understandings have suggested that such study is largely unnecessary.

The first basis for devaluing historical study came from philosophy of science, which was dominated by positivism during a century of rapid technological and scientific expansion (1860–1960). Although philosophers and scientists largely parted ways from the beginning of the twentieth century, it is fair to say that most practicing scientists during that period and beyond subscribed implicitly to the tenets of positivism, which spread beyond the physical sciences to the social sciences, medicine, economics, and wider culture. As defined by its originator, Auguste Comte, during the 1830s (and extended as *logical positivism* or *logical empiricism* from the 1920s), positivism concerns itself with observable quantities, rather than with theoretical constructions, to yield verifiable "positive knowledge" It argues that such empirical knowledge increases incrementally and inexorably over time. Its claim about the universality of expanding knowledge implies that all new science follows a reliable trajectory, beginning with imprecise speculations and even metaphysical descriptions and ascending to mathematical formulations and reliable predictions. A positivistic understanding of scientific knowledge suggests, then, that the detailed analysis of emerging subjects is largely pointless: any subject of worth will progress naturally over time in a regular fashion. And, because this process of observation is seen as universal, no one investigator or team is crucial in the long run. According to this view, writing the history of science need be little more than recording who added a new fact or quantum of information to the growing pyramid of knowledge, if it is worth acknowledging such a regular process at all. As physicist and historian of science Abraham Pais concluded regretfully of his contemporaries, "physics is an ahistoric discipline" [69].

A related understanding that became popular over the same century was *technological progressivism* and its more radical form, *technological determinism*. Based on the empirical observation of progress—the growing power, efficiency, economy, and complexity of machines, for example—it argues that this is a natural and irresistible process. Holographers' confidence in these ideas has been illustrated earlier in this chapter. Like positivism, progressivism assumes that applied knowledge will increase inevitably over time in a regular and natural manner. Simple devices will be the basis of better, more sophisticated mechanisms, and so there is an inbuilt tendency for improvement. Technological progressivists generalize and extend their claims considerably, though: they argue that the technical expansion that got underway during the nineteenth century is a template for all human societies. Indeed, Victorian writers were fond of citing the Industrial Revolution, and its prominent engineers, as a moral example of how hard work leads to more rapid inventive progress [70]. So-called *Whig history*, in which industrialized Britain, and later the Western world, became the exemplar of social, economic, and political advance, extended such notions of progress beyond science and technology to wider culture. Like positivists, progressivists argue for the universality of their claims, that is, that societies inevitably follow a trajectory of technological expansion and dependence, and that this technological development is a feature of an "advanced" society.

Even more contentiously, progressivism can be extended to determinism, which argues that this rolling process is largely beyond human control, and that societies naturally adapt to the inevitable progress of technology. According to determinists, societies will evolve in lock-step with their technologies, carried along on an relentless wave. As summarized by the motto of the Century of Progress International Exposition held in Chicago in 1933, the rather depressing determinist claim is that "Science Finds—Industry Applies—Man Conforms." Here again, the writing of technological history reduces to a list of heroes and dates. It also suggests that forecasting the future is a straightforward matter: inventions and technologies will continue to improve in an upward spiral, forever altering and benefiting society.

From the 1950s, however, philosophers and historians of technology began to turn away from such simplistic accounts of change. Thomas Kuhn, for example, argued that there have been many occasions in intellectual history when the corpus of knowledge changed abruptly rather than by following a smoothly ascending slope [71]. Rather than focusing on observation and experiment as the key ingredients to new knowledge, Kuhn and others stressed the seminal role of conceptual schemes. For Kuhn, the elaboration of *paradigms* is the central activity of new science: these conceptual frameworks could be tested, tweaked, and even terminated by empirical observations. Yet Kuhn's historical studies indicated that paradigms are not universal: they are constructed by groups of researchers, and can differ between them or be discarded following the *Gestalt* shift of a scientific revolution. His work opened the door to the consideration of social factors in the creation of new knowledge. Historians of technology, too, began to interpret "progress" as a culturally defined concept. Since Kuhn, the social and cultural aspects of science and technology have attracted an increasingly critical gaze.

Nevertheless, such new perspectives had little impact on practicing scientists, entrepreneurs, and the wider public, who had long been conditioned to expect continued scientific and technological change. The understanding of real-world sciences was pigeon-holed in two ways: either by being mapped onto the reassuring linear model of progress, and hastened by great men and their breakthroughs, or else relegated to the class of failed subjects, undeserving of attention. The "insider" and "outsider" interpretations of the subject diverged.

In any case, the case of holography does not follow these models well. As I have suggested, there was no breakthrough moment, but instead a characteristically tentative evolution of ideas. The subject of holography emerged after some twenty years of research in the subjects of wavefront reconstruction, wave photography, optical processing, and lensless photography in dissimilar intellectual contexts. Holography was not positivistic: rather than building on past knowledge, the subject was reinvented afresh in variant forms in different environments. And, in contrast to Comte's expectation, holography (at least for its countercultural advocates) accumulated layers of metaphysical interpretation as it aged, rather than shedding them.

Nor does holography conform well to later models of intellectual development that were introduced during the 1960s. For example, the subject was not a neat case of theoretical generalization, nor merely a series of fortuitous and experimental discoveries that mapped onto a conceptual scheme. Instead, we can identify periods during which the subject was shaped by different dominant influences. Between about 1947 and 1962, the subject was largely theory-driven. The work of Gabor, Rogers, El-Sum, Baez, Lohmann, Leith, and Upatnieks was impelled by slowly developing insights and generalizations and rewarded by gradually improving technical capabilities. Nevertheless, this was not a matter of testing competing theories, but instead separate, and seemingly disconnected, goal-directed searches.

Between about 1964 and 1972, by contrast, the subject expanded primarily by unguided experimental explorations. This is typified by the multiple occurrences of rediscovery and the proliferation of techniques and terminology for products. And between about 1972 and 1983, the subject was reshaped to suit the new communities that appropriated it. On the other hand, the dominant forces influencing the subject from the early 1980s were economic markets, increasingly steered by entrepreneurs having less technological commitment to the art of holography.

According to this periodization, holography sprouted successively as a subject (an intellectual domain with theoretical underpinnings), a medium (a collection of experimental techniques and products), an identity (a social locus for holographers), and a market (a collection of economically viable commodities, consumers, and application niches). This complicated evolution cannot be satisfyingly summed up according to the understandings of contemporary philosophers or sociologists of science. The appeal for the historian, then, is to chronicle this story in sufficient detail to encourage more convincing explanations.

Such exploration shows that as the cognitive boundaries of a technical subject shift, so, too, do its applications and users, and their criteria of success. Examples abound in holography of how "failures" and "successes" were interpreted inconsistently by shifting audiences. The various advocates of holography had distinctive aspirations; employed contrasting criteria to evaluate its goals, problems, and solutions; and buttressed their own differentiation in the process. Thus, Gabor's wavefront reconstruction was typecast as a technically constrained, and even backward-looking, microscopy during the 1950s, unworthy of forecasts. During the 1960s, the revitalized subject was widely understood in terms of photography, an analogy that directed predictions in ways that were difficult to sustain. Scientists, artists, and artisans portrayed their subject as potential-filled and judged it by its expansion, especially by the number of adopters. They had divergent definitions of good imagery, however, and so judged progress in conflicting ways. Was the technique developing toward metrological accuracy in a laboratory environment, colorful displays in shop windows, aesthetically nuanced fine art, the recording of public events, or an ubiquitous antiforgery product? Given the multiple constituencies, no consensus was possible, nor can any generally agreed attribution of progress be made. For the same reason, we cannot identify straightforward technological failure here. There was, however, a failure of technological forecasting, owing to overconfidence in short-term achievements made in an overinflated funding environment.

The history of the assessments and forecasts of holography has implications for other studies in the history of science and technology. As this subject demonstrates, historical evaluations of progress can be critically sensitive to appraisals made by different communities, particularly for unstable technologies that are adopted by distinct social groups. Each of them—such as scientists, the military, artists, businesspeople, and the public—may employ different criteria in judging the subject. And while we expect attributions of progress to depend on established or enunciated criteria, the case of holography shows that judgments have often been based almost entirely on implicit assumptions and superficial analyses. This is not unique, of course. Another historic example of such superficiality is the case of the New National Telescope, which astronomers widely judged a failure because it was never built. McCray [72] counters these assessments with the suggestion that the project could be deemed a success because of its liberating effect on telescope design, on promotion of international cooperation, and on public promotion of astronomy. Similarly, Elzen [73] argues that the Svedberg ultracentrifuge was seen as a successful artifact by his contemporaries despite its lack of influence on present-day designs.

Expectations for the trajectory of holography were supported by faith in both philosophical positivism and technological progressivism and fuelled by the expansive funding environment of the 1960s. The predictions of progress relied on little-examined assumptions and short-term forecasting, and its monitoring flavored subsequent judgments of success and failure. But re-examination of such assessments is difficult for such insecure subjects: lack of market penetration or professionalization can hinder the documentation of a field. This means that would-be sciences like holography have to be tracked by the historian as they evolve, not from scanty archival records. If not, there will be a tendency to underrepresent subjects that have not been judged progressive and successful by its contemporary practitioners and critics.

For a historian of science, holography further illustrates how consensus is not an inevitable outcome for debates in scientific subjects that do not reach disciplinary status, or for technologies that do not achieve commercial viability. It suggests that we be cautious about uncritical assumptions concerning the evolution of technological subjects: the inconsistent assessments of progress and success cannot be attributed merely to the youth of a subject or to inchoate relevant social groups. The notion of the "maturity" of a field is a problematic one and must be divorced from our own expectations of progress towards consensus. Not all technologies become black-boxed; some merely lose their supporters and relevance and are forgotten.

Gabor, the originator of holograms, was also a humanist in the Renaissance sense. An early member of the Club of Rome, he wrote and lectured in his later years on science and society and their entwined futures. One of his books, *Inventing the Future*, argued that while technological societies find themselves unable to predict the future, they can invent it for themselves [74]. Nevertheless, most outside observers today would probably agree that Gabor's claim, echoed by the engineers at Conductron and the MIT Media Lab, was not realized: the future did not turn out the way that engineers wished or expected. But, in altered form, the claim can be applied to predictions about the subject that Gabor initiated: the *imagined* future for holography has been reinvented repeatedly by successive waves of holographers, and continues to be recast by its subsequent communities and adopters.

As an historian, a dual perspective—namely explaining the past course of the subject alongside its imagined futures—has been my focus and is equally a matter of reinvention and interpretation. Exploring this subject, divided by contrasting assessments and predictions, it is apparent that the only indisputable failures surrounding holography concerned the forecasts themselves.

From a historian's point of view, then, holography represents a fascinating case of modern science and technology. It is a complex example of a surprisingly common but little noticed situation in modern science, in which a technical subject has created new communities and grown with them. Its evolution has been distinctly different from what most historians of science—and even holographers—might have expected, which can help us to better understand how modern sciences emerge, and how to more realistically chart their future trajectories. And because of the rich variety of communities that the subject has embraced, ranging from artists to defense contractors, its history is likely to be of enduring interest to broad audiences.

ACKNOWLEDGEMENTS

This work was supported, in part, by grants from the British Academy, the Carnegie Trust, the Royal Society, the American Institute of Physics' Friends of the Center for the History of Physics and the Shearwater Foundation. Portions of this work appear in S. F. Johnston, *Holographic Visions: A History of New Science*, Oxford University Press, Oxford (2006).

REFERENCES

1. P. Kirkpatrick, *Holography* 15, 9 (1968).
2. S. F. Johnston, *History and Technology* 20, 29 (2004).
3. L. Cross, *The Story of Multiplex* (1976). AQ2
4. D. Gabor, *Nature* 161, 777 (1948).
5. D. Gabor, *Proceedings of the Royal Society of London, Series A* 197, 454 (1949).
6. New Microscope Limns Molecule: Britons impressed by paper combining optical principle with electron method, *New York Times* (September 15, 1948).
7. M. Wolfke, *Phys. Zeitschr.* 21, 495 (1920).
8. W. L. Bragg, *Nature* 143, 678 (1939).
9. D. Gabor, Problems and prospects of electron diffraction microscopy, in *Conference on Electron Microscopy*, Delft (1949).
10. D. Gabor, *Proceedings of the Physical Society (London) B64*, 449 (1951).

11. P. Kirkpatrick and H. M. A. El-Sum, *Journal of the Optical Society of America* 46, 825 (1956).
12. H. M. A. El-Sum, *Reconstructed Wave-Front Microscopy,* PhD thesis, Stanford University, (1952).
13. A. V. Baez, *Nature* 169, 963 (1952).
14. G. L. Rogers, *Nature* 166, 237 (1950).
15. G. L. Rogers, *Nature* 167, 190 (1951).
16. G. L. Rogers, *Proceedings of the Royal Society of Edinburgh* A63 part III, 193 (1952).
17. A. W. Lohmann, *Optica Acta* 3, 97 (1956).
18. T. E. Allibone, *Journal of Electronics and Control* 4, 179 (1958).
19. S. F. Johnston, *Historical Studies in the Physical and Biological Sciences* 36, (2005, in press).
20. Y. N. Denisyuk, *Doklady Akademii Nauk* SSSR 144, 1275 (1962).
21. Y. N. Denisyuk, *Optika i Spektroskopija* 15, 522 (1963).
22. Y. N. Denisyuk, *Optika i Spektroskopija* 18, 276 (1965).
23. Y. N. Denisyuk and R. R. Protas, *Optika i Spektroskopija* 14, 721 (1963).
24. E. N. Leith and J. Upatnieks, *Journal of the Optical Society of America* 51, 1469 (1961).
25. E. N. Leith and J. Upatnieks, *Journal of the Optical Society of America* 52, 1123 (1962).
26. E. N. Leith and J. Upatnieks, *Journal of the Optical Society of America* 53, 522 (1963).
27. E. N. Leith and J. Upatnieks, *Journal of the Optical Society of America* 54, 1295 (1964).
28. S. F. Johnston, *International Conference on Holography, Optical Recording and Processing of Information*. SPIE, Varna, Bulgaria, (2005).
29. S. F. Johnston, *Physics in Perspective* 8, (in press).
30. *The incredible hologram*, Newsweek, December 29, 1969.
AQ3 *31.* S. A. Benton, *Optics & Photonics News* 41, (1994).
32. C. Charnetski, in *EASCON Convention*. IEEE, Washington DC (1970).
33. B. Latour, *Science in Action: How to Follow Scientists and Engineers Through Society*. Open University Press, Milton Keynes (1987). AQ4
34. S. L. del Sesto, in *Imagining Tomorrow: History, Technology, and the American Future*, J. J. Corn, ed. MIT Press, Cambridge MA (1986), p. 58.
35. S. F. Johnston, *Technology & Culture* 46, 77 (2005).
36. G. Youngblood, *Expanded Cinema*. Studio Vista, London (1970).
37. S. F. Johnston, *Proceedings of the SPIE—The International Society of Optical Engineering* 5005, 455 (2003).
38. T. Shinn, *Historical Studies in the Physical and Biological Sciences* 16, 353 (1986).
39. G. C. Kunkle, *Technology and Culture* 36, 80 (1995).
40. G. Gooday, *History and Technology* 14, 265 (1998).
41. B. Joerges and T. Shinn, eds. *Instrumentation: Between Science, State and Industry*. Kluwer Academic, Dordrecht (2001).
42. T. J. Pinch and W. E. Bijker, The social construction of facts and artifacts: or how the sociology of science and the sociology of technology might benefit each other, in *The Social Construction of Technological Systems*, W. E. Bijker, T. P. Hughes, and T. J. Pinch, eds, MIT Press, Cambridge, MA (1987), p. 17.
43. S. J. Douglas, *Inventing American Broadcasting: 1899–1922*. Johns Hopkins University Press, Baltimore (1987).
44. S. F. Johnston, *History and Technology* 21, (2005, in press).
45. S. Brand, *The Media Lab: Inventing the Future at MIT.* Viking Penguin, New York (1987).
46. D. Gabor, *Optik* 28, 437 (1969).
47. D. Gabor, *Proceedings of the SPIE The International Society for Optical Engineering* 25, 129 (1971).
48. E. Dolgoff, *Optical-Spectra* 9, 26 (1975).
49. Y. N. Denisyuk, *Journal of Applied Spectroscopy* 33, 901 (1980).
50. S. S. Shushurin, *Soviet-Physics-Uspekhi* 14, 655 (1972).
51. D. Gabor, *Fizikai-Szemle* 24, 289 (1974).
52. S. A. Benton, *Optics News* 16 (1977).
53. S. A. Benton, Ten years of white-light holography, in Electro-optics/Laser International 1980. IPC Science & Technology Press, Guildford, United Kingdom (1980).
54. E. N. Leith, *Proceedings of the International Symposium on Display Holography* 1, 1 (1983).
55. R. H. Jackson, *Holosphere*, 4, 5 (1983).
56. E. Wesley, *Holosphere* 15, 12 (1988).
57. R. de Marrais, *Holosphere* 12, 4 (1984).
58. T. H. Jeong, *Holosphere* 12, 18 (1984).
59. P. Greguss, *Optics and Laser Technology* 7, 253 (1975).
60. T. Albright, Holography's accelerating impact, *S. F. Sunday Examiner and Chronicle,* June 11, 1972.
61. A. L. Hammond, *Science* 180, 484 (1973).
62. P. H. Bringolf, *Proceedings of the SPIE The International Society for Optical Engineering* 2043, 319 (1994).
63. M. C. Bosco, *What Ever Happened to Holography?,* MA thesis, Harvard, (1981).
64. C. Milburn, *Configurations* 10, 261 (2002).
65. Corn, J., ed. *Imagining Tomorrow: History, Technology and the American Future*. MIT Press,Cambridge, MA (1986).
66. S. F. Johnston, *Holographic Visions: A History of New Science*. Oxford University Press, Oxford (forthcoming).
67. MIT Museum. *Strategic Plan, November 2000–June 2005* (2000).
68. MIT Museum*. DRAFT MIT Museum Collecting Guidelines for Holography* (2001).
69. A. Pais, *Niels Bohr's Times: In Physics, Philosophy, and Polity*. Clarendon Press, Oxford (1991).
70. S. Smiles, *Self-Help: With Illustrations of Character and Conduct*. John Murray, London (1859).
71. T. S. Kuhn, *The Structure of Scientific Revolutions*. University of Chicago Press, Chicago (1962).
72. P. McCray, *Technology and Culture* 42, 265 (2001).
73. B. Elzen, The failure of a successful artifact: the Svedberg ultracentrifuge, in *Center on the Periphery: Historical Aspects of 20th-Century Swedish Physics*, S. Lindqvist, ed, Science History Publications, Canton, MA (1993), p. 347.
74. D. Gabor, *Inventing the Future*. Secker & Warburg, London (1963).

Author Queries

AQ1: Is Science Year or Science Year Book the title?
AQ2: Please clarify what type of reference this is. If it is a journal article, supply volume and first page number. If it is a book, supply publisher and publisher's location (city, state/country).
AQ3: Please supply first page number.
AQ4: Location of publisher?