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Computer Science and Society in the ACM

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11 Other Places of Invention: Computer Graphics at the University of Utah

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11.1 Introduction

The history of computing in the U.S. is dominated by government-funded universities and private research institutions on the East and West coasts. MIT, Stanford, Harvard, UCLA, UC Berkeley, Bell Labs, Xerox PARC, and others played key roles in the early development of computer science and the transformation of that field into a large-scale industry. Often overlooked are those sites and institutions outside the research meccas of Silicon Valley and Boston's Route 128, spaces whose fundamental contributions to the history of computing have been largely forgotten, even by the institutions themselves.[1] The University of Utah is precisely this kind of place. Not only a major computer science research center of its time, it was also the premier institution for research into computer graphics in the United States for over 15 years. During roughly 1966–1979 the faculty and graduates of the Utah program were responsible for no less than inventing the concepts that make modern

1. In 2006 Professor H. Kent Bowen and Courtney Purrington, Ph.D., were commissioned to prepare a Harvard Business School case study on the University of Utah phenomenon by recently elected university president Michael Young. In 2004 Young learned of Utah's prestigious graphics history at the dedication of the new Warnock Engineering Building, named for Adobe Systems founder John Warnock, at which time there seemed very little institutional memory of the university's significant contributions. I draw on Bowen and Purrington's work in what follows, with particular interest to their original interviews with Utah faculty and alumni. See H. K. Bowen and C. Purrington. 2006. The University of Utah and the computer graphics revolution. Harvard Business School, Unpublished Case Study, April 28, 2006; revised April 11, 2007.

computer graphics possible. Some of the very first experiments with raster graphics, frame buffers, graphical databases, hidden surface removal, texture mapping, object shading, and more were conducted in the graphics lab in Salt Lake City, and many of the school's graduates went on to become industry leaders in the field. The Utah program served, in effect, as a testing ground for computer graphics in the decade leading up to the dramatic expansion of the Association for Computing Machinery's Special Interest Group on Graphics and Interactive Techniques (ACM SIGGRAPH) and the growth of what would eventually become the modern computer graphics industry.[2]

The Utah program's success was due in large part to the enthusiasm and dedication of a small handful of researchers in this very young field, and the faith and financial backing of several directors at the Advanced Research Projects Agency's Information Processing Techniques Office. Chief among these individuals was David C. Evans, a Utah native who was the founder and driving force behind the department, and who served as mentor to dozens of key figures. While Evans is by no means the only important figure in this history, the trajectory of influence that he holds over so many major players and developments in the field of computer graphics speaks to the unique environment he was responsible for cultivating at Utah in the 1960s and 1970s. At minimum it speaks to the culture of mentorship he fostered, which may be traced from these early moments to the "culture of innovation" promoted by so many Silicon Valley startups to come after it. The founders of Pixar, Adobe Systems, Silicon Graphics, Atari, Netscape, and WordPerfect were all students at Utah during this critical period. Likewise, key research centers at Xerox PARC, NASA, LucasArts, Pixar, and elsewhere were founded and populated by Utah alumni. The influence of the University of Utah program on the contemporary field of computing is massive, and is threaded throughout the field of computer science and its transformation into a commercial industry, yet it has until recently been largely neglected as a site for critical investigation.[3]

2. J. Brown and S. Cunningham. 2007. A history of ACM SIGGRAPH. *Commun. ACM*, 50(5): 54–61.

3. To be sure, the history of computer graphics does not begin with Utah. The development of early two-dimensional computer graphics finds its roots in the SAGE air defense system and with research teams at MIT, Lincoln Lab, and Harvard. Likewise, a great deal of early experimentation was conducted by artist-researchers such John and James Whitney, who explored rudimentary computer visualization through oscillography and early analog computing technology. See J. Hurst, M. S. Mahoney, N. H. Taylor, D. T. Ross, and R. M. Fano. 1989. Retrospectives I: The early years in computer graphics at MIT, Lincoln Lab and Harvard, and Retrospectives II: The early years in computer graphics at MIT, Lincoln Lab and Harvard. *SIGGRAPH '89 Panel Proceedings*, July 31–August 4, 1989, pp. 19–73. Association for Computing Machinery, Boston/New York; Z. Patterson.

Utah's peripheral status in the history of computing in many ways reflects the field of computer graphics as a whole, which has been dominated by these secondary sites and non-traditional institutions. This is due in part to the intersection of both research and artistic interests in this uniquely visual field, along with the broad trajectory that computer graphics would take over the course of its history—from the development of industrial applications for computer-aided design at General Motors to rendering software and computer animation at film studios such as Pixar, and contemporary applications in graphical user interface design, digital gaming, and data visualization. This is also due to the experimental nature of the work itself, and the fact that it was not until several decades of financial and intellectual investment that computer graphics became deployable outside of heavily funded university or industry contexts. Graphical visualization had long been a trope of early computing, particularly as it was popularized in other visual media such as film and television, but the computational requirements of visual computing were hugely demanding, making most early systems entirely unfeasible for large-scale deployment.[4]

The Utah program sought to change that, and was supported by a small network of researchers and funding entities that would make graphical man-machine communication—along with time-sharing and artificial intelligence—one of the primary research goals for the 1960s. While it would be more than two decades before interactive computer graphics would become an everyday reality for the vast majority of computer users, looking back there is little doubt that the Utah graphics program was a success. For better or worse, contemporary computing for the majority of users is effectively synonymous with computer graphics, as graphical interaction is the primary means by which we engage with computing today. What may be less clear is why the environment at Utah fostered such a brief but frenzied period of innovation, and what effect it may have had on the development of this emerging field.

This chapter asks why the University of Utah was so successful in its push to implement and commercialize computer graphics in this brief 15-year period.

Summer 2009. From the gun controller to the mandala: The cybernetic cinema of John and James Whitney. *Grey Room*, 36: 36–57.

4. The SAGE system required a massive four story building filled with millions of dollars of computing technology and manned by dozens of trained professionals in order to function, and even then there are doubts as to its ability to handle a "hot war" situation, if one had arisen; see P. N. Edwards. 1996. *The Closed World: Computers and the Politics of Discourse in Cold War America*, pp. 104, 110. MIT Press, Cambridge, MA.

I draw on a wealth of archival materials, with principal focus on the David C. Evans Collection of the University of Utah in Salt Lake City. The Evans papers are substantial and cover material related both to the Utah graphics program and its subsequent commercialization through the Evans & Sutherland Computer Corporation. Along with the Evans papers I have drawn from the papers of Thomas Stockham, who replaced David Evans as head of the Utah program in the 1970s, as well as the papers of James Fletcher, president of the University of Utah throughout much of the 1960s. I have also drawn on the Computer Science Department's own archival records, which include images of the graphics lab along with technical reports relating to the University's ARPA contracts and other research.[5] These are supplemented by oral histories from key researchers including David Evans, Ivan Sutherland, and Robert Taylor, as well as interviews with various Utah graduates. Finally, I have drawn on the ACM SIGGRAPH collections housed at University of Minnesota's Charles Babbage Institute to trace the institutionalization of graphical research, and to see the ways in which Utah research began to circulate within the emerging graphics industry.

In 2008, Jeffrey Yost, writing as the editor of the *IEEE Annals of the History of Computing*, clearly noted that "the history of computer graphics is an important topic that has been understudied, particularly for certain regions," and called on researchers to engage with the fifty year history of the discipline. To date, however, few have taken up this task. While recent years have seen a renewed interest in the Utah graphics program, both among historians of computing and by the University of Utah itself, there has been relatively little published on this history and its significance to the broader history of computing. The most significant contribution is Tom Sito's *Moving Innovation: A History of Computer Animation* (2013), which offers a valuable survey of computer animation in the United States from roughly 1950 to the present.[6] However, the book's breadth comes at the cost of attention to any single topic in great detail, and the history of the Utah program takes up little more

5. While less visible in this chapter, this work has been supplemented by the trade collections of the Smithsonian's National Museum of American History, as well as the Link Simulator Company's collection at the Smithsonian's National Air and Space Museum. I have also drawn on the Kurt Akeley Papers and the Russell Vernon Anderson Papers at the Stanford University Archives, as well as the collections of the Computer History Museum in Mountain View, CA. Finally, I have drawn on the Ed Catmull papers and several original oral histories housed at Pixar historical collections in Oakland, CA, and supplemented this work with my own original interviews with Alan Kay, Alvy Ray Smith, Richard Riesenfeld, and Al Davis.

6. J. Yost. 2008. From the Editor's desk. *IEEE Ann. Hist. Comput.*, 30(1): 2–3; T. Sito. 2013. *Moving Innovation: A History of Computer Animation*. MIT Press, Cambridge, MA.

than five pages. Likewise, while substantial monograph-length treatments of artistic experimentation with computer graphics during this early period have become quite common,[7] little attention has been paid to the significant contributions of the Utah program, which was largely responsible for establishing the field of computer graphics as an academic discipline and commercial technology prior to the founding of a dedicated special interest group through the ACM.

In what follows I outline the formation and first decade of the Utah graphics program, framing the kinds of social and professional networks that made the program possible alongside the institutional support that allowed it to thrive. I then examine the culture of mentorship that was fostered by the graphics program with particular focus on two of its lead faculty, David Evans and Ivan Sutherland. Drawing on an important trope of early graphics research known as the "ten unsolved problems," I look to frame the concerns of the then-nascent field of computer graphics while also suggesting that a future-oriented culture of problem solving helped bolster the Utah program and allowed for the rapid expansion that marks this early period of research. I conclude by discussing the program's afterlives and the large-scale shift away from government funded university centers and toward an emerging graphics industry, facilitated by the professionalization of computer graphics through the ACM and its SIGGRAPH special interest group. In doing so I reflect on the role of secondary sites in the history of computer science more broadly, and on computer graphics as a neglected but critical field for almost all contemporary computational applications.

11.2 Salt Lake City, 1966

Why, in 1966, did Salt Lake City become the epicenter for cutting-edge research into computer graphics? The answer is in some ways very simple. It was David Evans' decision to return to Salt Lake City—the city in which he was born and the home of his family and Mormon faith—that set in motion decades of innovative research into graphical applications in computing technology, along with the careers of dozens of key researchers in the field of computer science. In this sense the key role that Utah plays in this history is due largely to chance, or at the very least the

7. See P. Brown, C. Gere, N. Lambert, and C. Mason. 2009. *White Heat Cold Logic: Early British Computer Art 1960–1980*. MIT Press, Cambridge, MA; H. Higgins and D. Kahn, editors. 2012. *Mainframe Experimentalism: Early Computing and the Foundations of the Digital Arts*. University of California Press, Berkeley; and M. Rosen, editor. *A Little-known Story about a Movement, a Magazine, and the Computer's Arrival in Art: New Tendencies and Bit International, 1961–1973*. MIT Press, Cambridge, MA.

coincidence of birth and the belief in a kind of divine providence that makes Salt Lake City the holy center of the Mormon faith. The more difficult question, then, is how did this happen? What were the conditions that made possible this success, the structures that supported this work financially, culturally, and technologically? Put simply, how did the University of Utah as an institution come to support this highly experimental field of research? To answer this question we must begin with David Evans, as it is Evans' experience in the field of computing and his connections with government, academia, and industry that made this history possible.

Born in Salt Lake City in 1924, David Evans received his undergraduate degree in physics from the University of Utah in 1949 after interrupting his studies to serve in WWII.[8] He spent much of the following decade in California as a senior physicist at the Bendix Corporation in Los Angeles. At this early stage in the 1950s computing was a relatively small industry, with computer hardware often developed alongside other industrial electronics as part of contracts for the military or avionics industries. As such, Bendix was not exclusively a computing company, but in 1955 Evans was promoted to director of engineering of the Computer Division, which gave him the responsibility for research, development, and product design for commercial computing systems and special purpose information processing systems for military and industrial applications. While at Bendix, Evans was able to direct two of the company's most noteworthy projects: the Bendix G-15, introduced in 1955 and one of the first inexpensive general-purpose computers to be mass-produced; and the Bendix G-20, introduced in 1961. The chief designer for the Bendix G-15 was Harry Huskey, who had worked part-time on the early ENIAC computer in 1945, and later on the Pilot ACE at the National Physical Laboratory with Alan Turing. Huskey developed much of his research for the Bendix G-15 while a faculty member at UC Berkeley, and in 1962 Evans would follow him there, taking up a tenure-track position and leaving Bendix shortly before its computer division was taken over by the Control Data Corporation in 1963. It was during this period that he began working on projects funded by the Defense Department, serving as co-principal investigator (PI) for a four-year $1.5 million research initiative on computer-aided problem solving funded by the Advanced Research Project's Agency's Information Processing Techniques Office (ARPA IPTO).[9] By 1964 the project had evolved into the Project

8. Transcript, David C. Evans Oral History Interview, April 18, 1996, by Daniel Morrow, p. 11. Computerworld Honors International Archives.

9. David C. Evans (Curriculum Vitae), Box 18, Folder 10, Coll. 0199, James C. Fletcher Presidential Records, 1937–1971, University of Utah. For background on IPTO and graphics, see A. L. Norberg

Figure 11.1 **Bendix G-15 computer (designed by Alan Turing's colleague Harry Huskey) formed a link between Evans early work at Bendix and UC-Berkeley computer science.** (Image courtesy of the Charles Babbage Institute Archives, University of Minnesota Libraries)

GENIE time-sharing initiative, one of the earliest time-sharing systems ever built, and the earliest useful realization of time-sharing on a minicomputer.[10]

and J. E. O'Neill. 1996. *Transforming Computer Technology: Information Processing for the Pentagon, 1962–1986*, Chapter 3. Johns Hopkins University Press, Baltimore.

10. See L. P. Deutsch and B. W. Lampson. April 1965. SDS 930 time-sharing system preliminary reference manual, Doc. 30.10.10, Project GENIE, University of California at Berkeley; D. M. Ritchie and K. Thompson. 1974. The UNIX time-sharing system. *Commun. ACM*, 17(7): 365–375; M. A. Hiltzik. 1999. *Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age*, pp. 18–19. Harper Collins, New York; P. Spinrad and P. Meagher. Project Genie: Berkeley's piece of the computer revolution. Available at http://coe.berkeley.edu/news-center/publications/forefront/archive/forefront-fall-2007/features/berkeley2019s-piece-of-the-computer-revolution (accessed November 25, 2012).

It was also during this period that Evans began working with Ivan Sutherland, who in 1964 at the age of 26 had been made head of the IPTO and entrusted with a $15 million budget to continue and extend J.C.R. Licklider's vision of man-machine communication.[11] It was Sutherland who served as Evans' research sponsor at ARPA, and whose vision of *graphical* man-machine communication would have a substantial influence on the then-emerging field of computer graphics (indeed, Sutherland received the 1988 ACM Turing Award for "pioneering and visionary contributions to computer graphics"). While work on the time-sharing project at Berkeley was much smaller in scope than similar ITPO funded research sites of that time—most notably Project MAC at MIT—it produced a network of individuals with lasting ties to the IPTO. As Sutherland recalls, Project GENIE provided a training ground for researchers who would later make significant contributions to the field of graphics at Utah and elsewhere.[12] After two months as co-PI for Project GENIE Evans handed control over to Wayne Lichtenberger—a new visiting assistant professor at Berkeley—as his interests began to shift from time-sharing to graphics.[13]

It was in this context that Evans was approached by University of Utah president James Fletcher to return to his alma mater in Salt Lake City and found a computer science division within the School of Engineering.[14] By that time in 1965 Fletcher was a well-known research engineer in the aerospace industry, and had previously served as faculty at both Harvard and Princeton.[15] He had been appointed president of the University of Utah only one year prior in 1964, and one of his first moves was to recruit Evans. Fletcher's offer came with the full backing of the university, appointing him Director of Computer Science and Computer Operations at the University of Utah—a title intended "to indicate that [Evans would be] in charge of

11. Ivan Sutherland Oral History, Charles Babbage Institute, OH 171, p. 26. Available at http://purl.umn.edu/107642.

12. Ibid., 29.

13. Evans would return to time-sharing again in 1969 when Utah became one of the first four hubs in the ARPANET.

14. Hiring recommendation from U of U computer committee to James Fletcher, May 18, 1965, Box 18, Folder 11, Coll. 0199, James C. Fletcher Presidential Records, 1937–1971, University of Utah.

15. James Fletcher received his Ph.D. in Physics from CalTech in 1948. He was the son of the eminent Bell Labs scientist Harvey Fletcher, known as the "father of stereophonic sound" and credited with inventing the hearing aid. After serving at Utah from 1964–1971 Fletcher would go on to become the head of NASA from 1971–1977 and again for three years following the Challenger Space Shuttle disaster in 1986.

all aspects of computer work . . . at the university."[16] While university funds may have been limited, Fletcher's generous offer was supplemented by a $5 million grant from the IPTO that Evans was able to secure immediately following his hire. Paid out over the course of four years, the ARPA contract was devoted explicitly to "Graphical Man/Machine Communication" and was facilitated initially by IPTO director Ivan Sutherland who would leave government work that same year to take up a tenured position at Harvard University.[17] In the spring of 1965 Evans accepted the position at Utah, moving home to Salt Lake City in 1966 where he would remain for the rest of his life.[18]

To be clear, Evans is but one significant figure in this history. Nonetheless if we wish to understand why and how the Utah program was so instrumental to the development of early computer graphics, we must understand the central role Evans played in its formation and construction. Moreover, unlike many of the key players in this history who went on to found companies that have become household names over the past fifty years, the legacy of David Evans in the history of computing is little known outside of Salt Lake City, despite his central role in the shaping of our modern computing landscape. As this chapter will show, it is not possible to reconstruct the history of the Utah program through the biography of a single individual, as a range of historical actors both institutional and interpersonal played significant roles in producing the culture of research that made Utah so successful. Nonetheless there are key figures on which critical moments hinge, and whose vision shaped the field of computer graphics.

11.3 Practical Applications

In the mid-1960s few universities had programs let alone departments devoted to computational research.[19] Those programs that did exist were usually embedded within a larger primary department, the focus of which often dictated the research

16. Letter from Vice President J. A. Adamson to David C. Evans, June 16,1965, Box 18, Folder 12, Coll. 0199, James C. Fletcher Presidential Records, 1937–1971, University of Utah.

17. Ivan Sutherland Oral History, 11.

18. By all accounts Evans was happy at Berkeley, and prior to Fletcher's offer had no intention of leaving. In an oral history with the Evans family, Dave Evans' wife Joy Evans suggests that they expected to be in California the rest of their lives, but when Fletcher made the offer to Evans, the family decided to "come home." Transcript. April 18, 1996. David Evans Oral History Interview, 31.

19. The computer science program at Utah was the 14th degree-granting program in the United States.

direction that the computer science division would take. Frequently this would be a department of mathematics, the discipline out of which the theory of computing first emerged and where theoretical models for computation were actively researched. More practical applications in sub-fields such as computer graphics were often developed through corporate research centers such as AT&T Bell Laboratories[20] or General Motors Research Laboratories,[21] with clear ties to industry-based applications for computer interaction. It is therefore significant that the program at Utah was founded within the School of Engineering, and that its focus was on hardware applications over what Evans described as a tendency toward "mathematical models and abstract investigation."[22] This departmental focus reflected a culture of practice-based applications at Utah that attracted graduate students and faculty interested in making computer graphics deployable not only on a highly funded academic and military scale, but also for commercial use by corporations and individuals.[23] This is also one possible explanation as to why so many of the department's graduates and faculty would leave academia in the 1970s to enter the private sector, often commercializing the very technologies they had developed as IPTO-funded researchers at the University of Utah.

This emphasis on "real computing systems" speaks in many ways to the funding mission of the IPTO at this time. On paper its goal was the long-term development of technologies through the funding of creative research at key institutions, though at this early stage grants were given out largely as "visionary money" to key figures in this burgeoning field with no explicit result in mind. Instead, the program was driven by the creative vision of its director, J.C.R. Licklider, whose model for man-computer symbiosis served as the rallying cry for much ITPO-funded computational research throughout the 1960s, regardless of its potential application to any explicit form of military defense.[24] As Licklider recalled in 1988:

20. Z. Patterson. 2015. *Peripheral Vision: Bell Labs, the SC 4020, and the Origins of Computer Art*. MIT Press, Cambridge, MA.

21. F. N. Krull. 1994. The origin of computer graphics within General Motors. *IEEE Ann. Hist. Comput.* 16(3): 40–56.

22. P. Stewart. May 1968. Faculty profile: David C. Evans. Utechnic, University of Utah Engineering Publication, 10.

23. Indeed one of the origins of *personal* computing is arguably Alan Kay's "The Reactive Engine," which proposed a high-level kernel language called FLEX along with a "personal, reactive, mini-computer which communicates in text and pictures by means of keyboard, line-drawing CRT, and tablet" (vii). See A. Kay. 1969. The reactive engine. Dissertaton, University of Utah.

24. J. C. R. Licklider. 1960. Man-computer symbiosis. *IRE Trans. Hum. Fact. in Electron.*, 1: 4–11.

> the problems of command and control were essentially problems of man computer interaction [. . . so] why didn't we really develop an interactive computing? If the Defense Department's need for that was to provide an underpinning for command and control, fine. But it was probably necessary in intelligence and other parts of the military too. So, we essentially found that there was a great consonance of interest here, despite the fact that we were using different terms we were talking about the same thing.[25]

Under Licklider's plan there was no need to justify funding in terms of military outcomes, although there was a push for practical solutions to the problem of man-computer interaction in the long term. Unlike contemporary models used by funding bodies such as the National Science Foundation (NSF), one of the defining features of the IPTO under Licklider and his immediate successors was the *absence* of a peer-review system. The office functioned instead through a system of informal networks, whereby researchers with a proven ability to run large-scale projects that were known to IPTO directors were awarded large grants to pursue visionary research. It is through this network that Evans was able to secure the $5 million grant to pursue research into computer graphics at Utah.[26]

As Thierry Bardini has noted in his work on Douglas Engelbart and the Stanford Research Institute, this system created a network of insiders who had been graced with the approval of the IPTO, and who collectively shaped the direction of computational research in the U.S. for decades.[27] While Bardini is critical of this insider system for the way in which it excluded Engelbart's work on personal computing in favor of Licklider's vision of artificial intelligence, the Utah program would benefit greatly from this hands-off approach, which by many accounts fostered a culture of research that operated largely independent of any broader consensus of what an appropriate object for computational research might be.[28] As Gianna Walker

25. J. C. R. Licklider, Charles Babbage Institute, OH 150, pp. 24–25. Available at http://purl.umn.edu/107436.

26. It was also through this network, in part, that IPTO directors Ivan Sutherland and Robert Taylor would become University of Utah faculty in the years following their IPTO tenures.

27. T. Bardini. 2000. *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, p. 22. Stanford University Press, Stanford.

28. This hands-off approach is perhaps best exemplified by the incredibly brief semiannual reports written by Evans for the IPTO from 1966–1970. While the reports grow in length and complexity as the program expands, many are shorter than five pages long, offering little in the way of justification, favoring instead brief descriptions of hardware acquisitions and program goals. See D. Evans. Graphical man/machine communications. University of Utah, Semiannual Progress Report for period ending November 30, 1966. ARPA Contract AF30(602)-4277.

recalled in her brief history of the Utah graphics program at SIGGRAPH in 1994:

> They knew that they were "onto something big" while outsiders at other universities disparaged the work in computer graphics as an illegitimate application of computing machinery. Computing research at that time involved computer languages, operating systems, and data processing. Graphics research required manipulating so much data to display images, that it pushed the envelope in computing technology.[29]

Computer graphics research was impractical and unrealistic at this early stage. The technologies did not yet exist, and the computers themselves were not powerful enough to manipulate the massive amounts of data required for interactive graphical communication between a computer and its users. Yet despite these challenges IPTO directors viewed graphical interaction as central to the future of the field, and Evans was tasked with developing the technologies to make these systems possible. In this sense the isolation that Salt Lake City afforded was in fact beneficial to early research, as it allowed for a critical distance and sharp focus on what at that time may have seemed to many researchers outside the IPTO as an improper field of inquiry.

The majority of Licklider's early funding initiatives were in the field of artificial intelligence at institutions such as Stanford, Berkeley, and MIT. It was his successor, Ivan Sutherland, who organized an explicit program to fund graphics research when he took over as director of the IPTO in 1964. By 1965, Sutherland had implemented the Graphic Control and Display of Computer Processes program, whose stated goal was:

> to couple the advanced computer drawing techniques now available with complex internal computation programs. Such coupling will make it possible to control complex computation by drawing and display the results of the computation as drawings . . . The aim is to build tools necessary for controlling a wide variety of computations graphically.[30]

At that time Sutherland was arguably the most prominent researcher in the field of computer graphics, due largely to his doctoral dissertation at MIT, completed only one year prior to his appointment at IPTO. Titled *Sketchpad: A Man-Machine Graphical Communication System* (1963), it is arguably one of the most influential

29. G. Walker. 1994. The inception of computer graphics at the University of Utah 1960s–1970s. (notes from panel at the annual meeting of the Association of Computing Machinery's SIGGRAPH, September 27, 1994). Available at http://archive.today/lADGG.

30. Sutherland quoted in Norberg and O'Neill, *Transforming Computer Technology*, 128.

documents ever written by an individual for its vision of how a user could interact with a computer graphically.[31] For Sutherland visual images were essential tools for understanding complex computational problems, and the funding initiatives of the IPTO during his directorship from 1964–1966 reflect this strong interest. Central to this vision was the funding of the Utah program both by Sutherland and his successor Robert Taylor, who pushed Evans to build a Center of Excellence for computer graphics research at Utah, making it the flagship program for computer graphics research in the U.S.[32] The notion of a Center of Excellence was a key part of ARPA's funding model at this time. First implemented in its Material Science Program, ARPA would find individuals with strengths in a particular field and funnel research funds into that program in the hopes of creating a hub of expertise and collaboration.[33] In effect IPTO would invest money in a field through a single institution and often by way of an individual scholar. If a particular institution failed to coalesce as a Center of Excellence it would be defunded and resources could be allocated elsewhere. This was the case with ARPA's efforts at the University of Michigan to fund a major computer graphics project called Conversational Use of Computers (CONCOMP). At Michigan the objective was to provide theory and programs for a general network service system which, through the use of computer graphics in a conversational mode, would allow researchers to specify specialized graphical problem-oriented language systems for the description and solution of diverse network problems. While the CONCOMP program continued until 1970, the University of Michigan did not evolve into an IPTO center of excellence, and as such its graphics program was not considered a success; it was defunded by the IPTO in 1968.[34]

By funneling money and resources in this focused way, the IPTO was able to concentrate efforts in a particular field and create long-lasting collaborations and connections. While the concentration of talent in particular universities was an asset for focused collaboration, it also created challenges for collaboration between ARPA-funded programs. This was, in part, the justification for ARPA's interest in time-sharing technology, and the funding and development of the ARPANET beginning in 1969 under Robert Taylor. If each research center functioned as a hub,

31. A. Blackwell and K. Rodden. 2003/1963. Preface to this electronic edition. In *Sketchpad: A Man-Machine Graphical Communication System*. Cambridge University Online, Cambridge.

32. Robert Taylor Oral History Interview, October 10–11, 2008, by Paul McJones, p. 16, Computer History Museum.

33. Ibid.

34. Norberg and O'Neill, *Transforming Computer Technology*, 128.

networking those hubs could tap into the expertise and technical resources of the others.

Here we begin to see the institutional infrastructure that made the Utah program possible. It was Evans' experience with the IPTO at Berkeley and his connections to individuals and funding bodies that put him in the position to take on a field of research that was viewed by others as impractical or illegitimate. This institutional network was further enhanced by the administrative framework of the IPTO, in which full trust was granted to Evans and little oversight given as to the direction of his work. This isolation was mirrored in the remote location of Salt Lake City itself. Removed but not inaccessible, this geographic and institutional context allowed for a robust Center of Excellence to grow that would attract dozens of key researchers from around the world who would build a unique culture of innovation over the next fifteen years. How then did Evans and his colleagues take on this task of building a field of research where no framework existed? Where does research begin when no model exists for the objects at hand?

11.4 Problem Solving

While it was Evans' job to build a computer science department that would serve the general needs of the University, his primary focus from the very beginning was research into computer graphics. As Evans described it:

> One interesting thing about starting a new department at a university is there's nothing going on when you get there. There's no equipment and no students and no money, and so you can do one thing as easily as you can do anything else. And so that's when I decided that I ought to be a computer graphics expert, and so I declared myself one and we started.[35]

This narrow focus was a tactical decision. Rather than attempt to compete with other computer science programs at leading research institutions, Utah would focus most all its efforts on one thing only: computer graphics.[36]

35. History of Evans & Sutherland part 1. Audio Recording, June 17, 1977, 07:14–07:50 David C. Evans audio-visual collection A0159, Special Collections and Archives, University of Utah.

36. While graphics was the department's focus, initially there were four specific areas of research: the Computer-Aided Architectural Design System project, headed by Stephen L. Macdonald, from the department of Architecture; the Left-Ventricular Dynamics Project headed by Dr. Homer K. Warner from the Department of Biophysics, a group focused on "The Use of Graphics in the Solution of Partial-Differential Equations" headed by the director of the Computer Center Louis A. Schmittroth, and David Evans' Computer Graphics Techniques division. See D. Evans. May 1968. Computer science at the U of U. Utechnic, University of Utah Engineering Publication, pp. 12–13.

Evans' initial focus at Utah was establishing the computer science division within the School of Engineering, and from 1966–1967 he used his IPTO funding to set up a Computer Center designed to serve the large scale computational needs of the entire campus. Within this Center Evans installed a laboratory built specifically for research into graphical applications. Initially, the Computer Center was set up with an IBM 7044, an early transistor computer released in 1963 but quickly made obsolete by the IBM/System 360 family in 1964. The Center soon replaced the IBM with a UNIVAC 1108, which utilized integrated circuits and allowed for simultaneous handling of real-time applications, time-sharing, and background batch work. This main computer system was then connected to the Graphics Laboratory through a PDP-8 minicomputer that was modified to provide both extended interrupt logic and the analog output required to drive the half-tone cathode ray tube. The PDP-8 was then connected to two graphics facilities, or workstations.

The first workstation was called the Line Graphics Terminal and was composed of a 21-inch cathode ray display with a light pen. The terminal was driven by a line generator and a 64-character symbol generator constructed by Information Displays Incorporated.[37] As its name implies, this terminal was used primarily for simple vector graphics composed of wire frames with no surfaces or shading. This kind of graphical output was relatively simple and had been possible since the early 1960s, but prior to this period it was extremely difficult to produce realistic images with hidden lines removed. The second workstation was the Half-tone Graphics Terminal, which consisted of a modified laboratory oscillograph driven through a digital-to-analog converter by the PDP-8. This terminal would be used for more general-purpose computer graphics services such as line drawings and symbolic displays with light-pen pointing and tracking. The half-tone terminal had the initial capability of displaying half-tone representations of two-dimensional projections of three-dimensional objects generated by the Univac 1108 and PDP-8 computers. This was the primary workstation for early graphics research, and was used in the efforts to solve key problems in representing three-dimensional graphical objects.

The primary objective of the department at this early moment was "to develop a means to produce photograph-like pictures of complex illuminated objects at a reasonable cost."[38] As Evans described in his first ARPA report:

> A major objective of the project is to develop a method which will produce synthetic video signals representing two-dimensional projections of three-

37. D. Evans. 1966. Graphical man/machine communications. University of Utah, Semiannual Progress Report for period ending November 30, 1966. ARPA Contract AF30(602)-4277, p. 2.

38. Evans, Computer science at the U of U, 13.

> dimensional objects described only in the data structure of the computer. It is considered that such a representation of the object is of basic value, because it corresponds to the representation of the real world on the human retina.[39]

What may sound simple enough by contemporary standards was a massive undertaking at the time, and presented a number of challenges that had never before been addressed by computer science. Evans outlined these challenges explicitly in an early report on the computer science department published in the University of Utah's own engineering publication *Utechnic*:

> In order to do this, three important problems must be solved: 1) A good means must be found so that only visible surfaces are displayed in the picture. 2) Half-tone shading determined by instant light must be provided. More information beyond that provided by line drawings is given by this means. 3) A good model must be found for representing arbitrarily shaped surfaces.[40]

This method of formulating research goals as problems in need of solution was an important trope for early computer graphics, as it helped to focus and organize this otherwise disparate field of research. By positing technological development and change in terms of actionable problems, researchers created a motivational structure in which otherwise abstract goals such as graphical development or visual mimesis were understood as identifiable problems that were always progressing toward a more accurate or realistic solution, even as Evans' initial goal of true photorealism remains a receding horizon to this day.

Evans was not alone in this problem-solving formulation. Indeed this is a central concept for the modern sciences, and arguably the primary interest of the various branches of engineering, concerned as they are with the design, analysis, and development of technological solutions. Nonetheless, the trope of unsolved problems takes on a particular valence in computer graphics to become a kind of call to arms, a means of mobilizing a disparate group of researchers to a clearly defined set of tasks. This formula begins—as with so many things in computer graphics—with Ivan Sutherland and a brief six-page article written for the journal *Datamation* in 1966.[41] Titled "Computer Graphics: Ten Unsolved Problems," the article became a critical framework for computer graphics researchers for over fifty years, revis-

39. Evans, Graphical man/machine communication, 3.

40. Evans, Computer science at the U of U, 13.

41. The article is often incorrectly cited as "Ten unsolved problems in computer graphics," which has since become the standard formatting for the phrase. See I. Sutherland. 1966. Computer graphics: Ten unsolved problems. *Datamation*, 12(5): 22–27.

ited time and time again as old problems were solved and new problems arose.[42] The article is arguably one of Sutherland's most famous works,[43] as it articulates a particular vision of the future for the field of computer graphics written by the then-director of the IPTO, a set of key problems that suggest a trajectory that researchers might follow.

The article is structured around what Sutherland then viewed as "a representative sample of the topics of interest to today's researchers in on-line computer graphics,"[44] and it consists of little more than a brief introduction followed by ten unnumbered sections, each detailing a single problem. Yet despite its relative brevity, the article would set the field's research agenda for over a decade. For Sutherland in 1966, the key unsolved problems in computer graphics were:

- Hardware Characteristics & Cost
- Problems of Technique
- Coupling Problems
- Describing Motion
- Halftone Capability
- Structure of Drawings
- Hidden Lines
- Program Instrumentation
- Logical Arrangement
- Working with Abstractions

42. See J. Blinn. 1998. Ten more unsolved problems in computer graphics. *IEEE Comput. Graph. Applic.*, 18(5): 86–89; M. Newell and J. Blinn. 1977. The progression of realism in computer generated images. *ACM '77 Proceedings of the 1977 annual conference*, pp. 444–448. ACM, New York; P. Heckbert. 1987. Ten unsolved problems in rendering. *Workshop on Rendering Algorithms and Systems*, Graphics Interface 87, Toronto, April 1987; M. Levoy. 1996. Open problems in computer graphics. Last updated April 8, 1966. Available at http://graphics.stanford.edu/courses/cs348b-96/open_problems.html; and J. Foley. 2000. Getting there: The ten top problems left. *IEEE Comput. Graph. Applic.*, 20(1).

43. Sutherland is best known for his *Sketchpad* work, but is also well known for his early writing on virtual reality and computer graphics. See I. Sutherland. The ultimate display. *Proceedings of IFIP Congress 1965*, pp. 506–508. Available at http://worrydream.com/refs/Sutherland%20-%20The%20Ultimate%20Display.pdf.

44. Sutherland, Ten unsolved problems, 22.

Examining these problems offers us a glimpse into the state of computer graphics at the very moment the field emerged as a coherent technical discipline, and the very same year that the Utah graphics program was founded. Perhaps surprisingly, the vast majority of the issues Sutherland outlined have little or nothing to do with image, picture, or vision. Instead Sutherland's concerns are for things like *Coupling Problems*, which dealt with the interfacing of graphical hardware with software and related systems; *Program Instrumentation,* which dealt with the standardization of program syntax and structure such that the relationship between parts of a program was clear and apparent; and *Hardware Characteristics and Cost*, which concerned the massive price tag of experimental hardware and the need to develop standardized tools that could be mass produced at a reasonable cost.

Only three of the problems deal specifically with the challenge of producing graphical object simulation itself: *Halftone Capability*, *Hidden Lines,* and the *Structure of Drawings*. *Halftone Capability* is the ability to shade solid objects so that they appear realistically opaque, which in turn leads to the simulation of surface effects such as lighting, color, and texture. *Structure of Drawings* deals with the standardization of object forms, and the kinds of geometric primitives that could be legible to a computer graphical program. By far the most visual concern is that of *Hidden Lines*, which dealt with a computer's ability to tell which lines in a given drawing should be made visible to a viewer.[45] These three problems outlined the minimal requirements for graphical realism in 1966, and they demanded a novel set of solutions not yet imagined.[46] Unsurprisingly, these problems map directly onto the three goals that Evans outlined in his own report on the state of his department in 1968, and from 1966–1970 these problems were the focus of a great deal of research at Utah, with multiple competing solutions developed for each.[47]

45. J. Gaboury. 2015. Hidden surface problems: On the digital image as material object. *J. Vis. Cult.*, 14(1): 40–60.

46. It is significant how distant these goals are from contemporary research into graphical realism, and how little explicit reference there is to the appearance of objects beyond the most basic attributes of visibility. As Jim Blinn noted in his keynote address at SIGGRAPH 1998, it wasn't until the 1970s that rendering became a primary interest for graphics research. At this stage researchers are concerned with "interaction problems," that is, the way objects and systems connect and interrelate. See J. Blinn. February 1999. "SIGGRAPH 1998 keynote address. *Conference Reports*, 32(1). Available at http://old.siggraph.org/publications/newsletter/v33n1/columns/conf.html.

47. One exemplary work is John Warnock's solution to the hidden surface problem, which was a major milestone of the time but was ultimately replaced by more efficient solutions such as Edwin Catmull's z-buffering. See J. E. Warnock. 1969. A hidden surface algorithm for computer generated halftone pictures. No. TR-4–15, University of Utah, School of Computing; E. Catmull.

While these problems may seem inconsequential when viewed through the lens of contemporary computer graphical challenges, it is important to note that many of the solutions that were first developed in the 1960s and 1970s continue to underpin a wide range of contemporary graphical techniques such as smooth shading, z-buffering, ray tracing, and more. The persistence of these solutions speaks directly to their historical significance, but it also helps make clear why narratives of technological development—what computer scientist and Utah graduate Jim Blinn (Ph.D. 1978) has called the "quest for realism"—have played such a powerful role in the evolution of the field toward more realistic and lifelike simulations. Through the trope of the "ten unsolved problems," realism becomes a problem that can be solved incrementally. As solutions to some problems are developed, a new set of ten problems would be published. Since Sutherland's initial article in 1966 an updated list has been published at least once a decade by various authors, suggesting that problem solving continues to be a primary framework by which the field is defined and research is framed. It begins in 1966 with ten unsolved problems; but to solve these problems Evans would need to recruit top-tier faculty and graduate students and begin to shape a community of researchers interested in making his vision of interactive graphics a reality.

11.5 Community

In its first five years the University would pull in dozens of researchers to this young program in Salt Lake City, although in 1968 the program came close to losing Evans altogether. After leaving the IPTO for Harvard in 1966, Ivan Sutherland remained in close contact with Evans and his family; and by 1967 the two began to discuss the possibility of founding a company to capitalize on the work being done at Utah.[48] Initially, they decided it would be best to move the venture East to the then-flourishing tech scene along Route 128 in west suburban Boston.[49] Despite the

1974. A subdivision algorithm for computer display of curved surfaces. No. UTEC-CSC-74–133, University of Utah, School of Computing.

48. David C. Evans Oral History Interview by Daniel Morrow. Computerworld Honors International Archives, p. 15.

49. There were also concerns over the potential conflict of interest with Evans' responsibilities at the University. Evans had worked specific language regarding his ability to perform contract work into his initial hire, but E&S served to magnify these concerns, leading to an explicit policy enacted by the University intended to marginally restrict commercial ventures such as E&S. See Proposed policy statement on conflict of interest. David C. Evans papers, Ms 625, Box 5, folder 1. Special Collections and Archives. University of Utah.

advantages Salt Lake City offered to a community of innovative researchers backed by the IPTO, it was far from the tech industry hubs of the time and the regional advantage they might afford.[50] Nonetheless, having just moved from California along with their seven children one year prior, the Evans family was not excited by the idea of leaving so soon. As Sutherland recalled:

> Joy Evans, Dave's wife, reasoned with him. She said, 'Dave, we have seven children, and Ivan has only two. It would be much easier for Ivan to move to Salt Lake than for us to move to Boston.' And I believe that was the seed of the University of Utah phenomenon.[51]

Sutherland moved with his family to Salt Lake City in 1968 to co-found the Evans & Sutherland Computer Corporation (E&S), accepting a tenured position at the University of Utah which he would hold until 1974. It is difficult to overestimate the centrality of E&S. It was the first computer graphics firm in the country, and many of the key technologies developed at Utah were produced either in partnership with E&S or transformed by E&S into commercial technologies. The company also served as an important resource for many of the Utah graduates who worked as employees for E&S both during their time as graduate students and/or on completing their degrees. E&S served as the platform from which a large number of Utah graduates launched their careers, and it is through the technologies produced by E&S that the research of the Utah program received wide circulation in the growing commercial graphics industry. The company was in effect a key partner organization with the Utah graphics program, and helped to both facilitate the transition from academia to industry in the 1970s, as well as to support a community of researchers beyond their careers as doctoral students at the university.

With Sutherland on board in 1968, Evans spent the next several years recruiting key faculty with the support of university president James Fletcher. Immediately following Sutherland Evans recruited Robert Barton, the chief architect of the Burroughs B5000 and inventor of the first stack machine architecture implemented in a mainframe computer. In 1969 he hired Thomas Stockham from MIT who began an innovative program of signal processing research that would lead to some of the earliest work in the field of digital recording. Stockham would later succeed Evans as department chair in 1972. In 1970 Evans recruited Charles Seitz from MIT, who

50. A. Saxenian. 1994. *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*. Harvard University Press, Cambridge, MA.

51. H. K. Bowen and C. Purrington, April 28, 2006. The University of Utah and the computer graphics revolution. Harvard Business School, Unpublished Case Study, revised April 11, 2007), p. 5.

Figure 11.2 **Ivan Sutherland with David Evans at University of Utah.** (Courtesy of © University of Utah archives)

played a critical role in the development of asynchronous circuits and would later found the high performance interconnect and switching company Myricom. While several faculty would leave the University by the early 1970s, this rapid expansion was crucial to the program's success. In just a few short years Evans had amassed a distinguished faculty drawn from top-tier research institutions across the country. While the resources afforded by the university and the IPTO were a significant draw for faculty hires, a major key to this success was Evans' own leadership and enthusiasm for the work being done at Utah.[52] As John Warnock recalled,

52. Evans personal correspondence, along with interviews and oral history from faculty and graduate students, makes frequent mention of the natural resources of the Salt Lake City region, with particular interest in the accessibility of local ski resorts.

"Dave had the ability to get people excited. I just think he was a phenomenal motivator for getting people to come and work on important things."[53]

This penchant toward community building was also reflected in Evans' policies on graduate admissions, which were designed to seek out hard-working and creative students regardless of academic record. As Sutherland recalled,

> David was clever about admitting students who had unusual records. He decided that in every class we're going to admit a few outliers, folks who were clearly interesting, but for whom the academic system didn't exactly fit. That was quite a conscious admissions policy.[54]

Evans' goal was to create an environment in which students would thrive with few rules and as much responsibility as they could take on. In his first meeting with Evans in 1969, Al Davis (Ph.D. 1972)—now director of the University of Utah School of Computing—recalled asking what course requirements there were for the department. The answer: "There aren't any. Talk to the faculty, find out what you're interested in, then do great research and do great things."[55] This largely unstructured environment, along with the mentorship of Utah faculty, was key to the success of the department and its graduates.[56]

Students were allowed to form their own collaborations and were encouraged to focus narrowly on the key problems facing the field with the goal of finding broadly deployable solutions. These problems often served as the impetus for Ph.D. theses, many of which remain the *de facto* solutions for contemporary graphical software and hardware. The department's first student was Stephen Carr (Ph.D. 1969), who followed Evans from Berkeley and conducted early research on geometric mod-

53. Bowen and Purrington, University of Utah and the computer graphics revolution, 5.

54. Ibid., 8.

55. K. J. P. Lindberg. 2006. Pioneers on the digital frontier. *Continuum: The Magazine of the University of Utah*, Winter 2006–2007. Available at http://continuum.utah.edu/2006winter/feature3.html. This anecdote was also recounted in an interview with the author on March 21, 2012 in Salt Lake City.

56. It can be difficult to properly historicize a community of practice and the ways in which it contributed to a culture of innovation at a specific period in time. This is particularly true when that history is by necessity be colored by the nostalgia of living historical actors whose time at Utah was by many accounts fundamental to their later success. Oral history and interviews with Utah faculty and students are often filled with evocations of pioneering research and cowboy computing, claims whose narrative of exceptionalism mirrors the historical narrative of the Salt Lake City region itself. While it is important not to discount these narratives, it is equally important to remain critical of their historical utility.

eling.[57] Soon after in 1966 Evans recruited Alan Kay (Ph.D. 1969), whose graduate research would form the basis for his pioneering work on object-oriented programming and the graphical user interface design at Xerox PARC in the 1970s. Kay's atypical academic background speaks directly to Evans' admissions policies during this period. In 1961 Kay had been expelled from Bethany College in West Virginia after participating in a protest of the university Jewish quota before joining the volunteer air force to work as a computer programmer, returning to finish his B.S. in Mathematics and Molecular Biology at the University of Colorado Boulder.

Ivan Sutherland also played a significant role in graduate student recruiting during this period. While Evans was setting up the department in Salt Lake City, Sutherland made multiple trips to MIT to recruit potential graduates. He also travelled internationally to France, where he believed the most innovative mathematical research was being done,[58] and recruited several key graduates from the National Institute for Research in Computer Science and Control (INRIA) in Rocquencourt and the École Polytechnique in Palaiseau.[59] Most notable among them were Henri Gouraud (Ph.D. 1971) and Bui Tuong Phong (Ph.D. 1973), each of whom developed unique solutions to the problem of object shading still widely in use today.[60]

The department also drew in local students from the Salt Lake City area, many of whom had not initially intended to pursue computing or graphics, but found themselves at the center of Evans and Sutherland's research community. Early Utah locals included Nolan Bushnell (B.S., 1969), who would later found Atari, Inc. in 1972, and Alan Ashton (Ph.D. 1970), who developed WordPerfect in 1979. Evans and Sutherland frequently poached promising students from other departments, such as physics or mathematics, to join the growing computer science program. John Warnock (Ph.D. 1969) recalls that, "[after] working for about three years on a Ph.D. in mathematics . . . Dave took all of the mathematics and applied it

57. For a comprehensive list of Utah graduates, see Ph.D. alumni, School of Computing, University of Utah. Available at http://www.cs.utah.edu/~sgoyal/soc/phd.html (accessed January 2016).

58. During the 1970s and 1980s French computer scientists would make significant contributions to the field of computer graphics. Among them are Gourard and Phong, but the list would also include Pierre Bézier—one of the founders of the fields of solid, geometric, and physical modeling as well as in the field of representing curves, particularly in CAD/CAM systems—and Benoit Mandelbrot, who popularized fractal geometry.

59. Jim Crow, Unpublished email interview with Peter Shirley, November 8, 1996.

60. H. Gouraud. 1971. Computer display of curved surfaces. No. UTEC-CSc-71–113, University of Utah, School of Computing; B. Tuong-Phong. 1973. Illumination for computer-generated images. University of Utah, School of Computing.

toward the coursework for the College of Engineering's Computer Science Ph.D. Consequently, I've never had a course in engineering."[61] Warnock's dissertation produced a key solution to the hidden surface problem described above. He would go on to work at E&S and Xerox PARC in the 1970s before founding Adobe Systems in 1982.

In these first five years the department thrived. With a steady influx of funding and researchers they were able develop workable solutions to a large number of key problems with the full support of the IPTO, whose cavalier attitude over funding and resources facilitated rapid expansion and innovation. As Alan Kay recalled in one particularly colorful anecdote:

> I remember once, after being at Utah for three or four months, Dave was saying in the midst of some other conversation that was going on, "We're almost out of money. Got to go get some more." So he got on a plane, and three days later came back with our next ARPA contract. That was the way they did it in those days. People did not generally write big proposals.[62]

But by the early 1970s all this began to change, due in no small part to the passing of the Mansfield Amendments by Congress in 1970 and 1973. The two amendments, named after Montana Democratic senator Mike Mansfield, severely limited the use of military funds for the kinds of long-term visionary grants that were the hallmark of the Licklider-era IPTO. If a project had no explicit military application, it could no longer be funded by the Defense Department. This newfound administrative oversight crippled many of the Centers of Excellence that had been founded over the previous decade, and had a dramatic impact on the future of the Utah program. Applications and reports to the Defense Department grew noticeably in length and complexity during this period, as funding became much more difficult to acquire. The old boys club of the 1960s was beginning to come under heavy scrutiny, despite the demonstrable success of many IPTO initiatives. This transformation is clearly visible in an exemplary letter from the program manager for the DARPA Cybernetics Technology Division to David Evans in 1977, in which he chides Evans for his proposal on software and database production:

61. Bowen and Purrington, University of Utah and the computer graphics revolution, 9.

62. Ibid., 6.

> I appreciate short, no baloney proposals, but this one may have gone a little too far. I need some more information. (You might also want to clean up the spelling mistakes and use the correct name of our agency.)[63]

What follows is a list of 12 bullet points to be answered, and a request for a revised budget sheet.

Of course, research into computer graphics did not stop. It simply changed venues. As ARPA funding dried up, the IPTO's Centers of Excellence began to hemorrhage researchers, who in many cases turned to jobs in the burgeoning computer industry. One notable exception was the graphics group at the New York Institute for Technology, a largely self-funded initiative driven by the eccentric vision of its founder Alexander Schure. At NYIT Ed Catmull (Utah Ph.D. 1974) and Alvy Ray Smith made early strides in computer animation prior to their move to Industrial Light and Magic in 1979 and the founding of Pixar in 1986.[64] With the founding of ACM SIGGRAPH in 1969 and the first annual conference on computer graphics in 1974 the field began to professionalize and move beyond the largely academic context of its first decade. Over the course of the 1970s SIGGRAPH and the ACM served as key venues for graphical research, and helped support a growing network of researchers transitioning from early unsolved problems to commercially deployable applications. In this sense the ACM served as a bridge between research and industry at the very moment in which the field was transitioning away from academia toward new funding and research models.

Over the course of the 1970s research centers at Xerox PARC, NASA's Jet Propulsion Laboratory, and the New York Institute for Technology were populated with Utah faculty and graduates who brought with them years of experience, as well as research results that could be capitalized on by corporate initiatives. Evans & Sutherland continued to grow as well, due in part to its ability to secure Defense Department funds for research and development in the emerging field of military and commercial flight simulation. By the end of the decade David Evans had largely left academia to pursue commercial graphics full time, resigning as chair of the

63. This final jab refers to the 1972 name change from ARPA to DARPA, adding the word "Defense" to signal this shift in priorities. See Letter to David Evans from Craig Fields, David C. Evans papers, Ms 625, Box 89, folder 2. Special Collections and Archives. University of Utah.

64. See A. R. Smith. 2001. Digital paint systems: An anecdotal and historical overview. *IEEE Ann. Hist. Comput.*, 23(2): 4–30.

Computer Science Division of the University of Utah in 1972 before leaving the university entirely in the early 1980s.[65] By 1979 the golden era of the Utah program was over, but the network of researchers that began their careers at Utah was firmly established, and would grow to have a massive impact on the field of computing as it became increasingly graphical and interactive.

11.6 Other Places[66]

The history of the Utah graphics program is significant for many reasons. First, it offers an exemplary history of institutional success in which funding, leadership, administration, and talent all aligned to jump-start a field of inquiry decades ahead of its time. I have attempted here to articulate precisely why this happened and how each of these key players contributed to the success of computer graphics at Utah during this brief but influential period. Nonetheless the Utah story points to something much larger than this 15-year regional history. Looking back it may be surprising to some that a program so geographically isolated from the technical research and economic centers of the U.S. could succeed in the way that it did, but as this chapter has shown the program was by no means outside the critical networks of influence that funded and fed computer science during this early period.

Nonetheless, the field of computer graphics as a whole is dominated by these secondary sites, by spaces where we might not expect technological development to thrive. From some of the earliest experiments in vector graphics by artist and draftsman Ben Laposky of Cherokee, Iowa, in 1950,[67] to the first use of the term "computer graphics" in 1960 by Verne Hudson and William Fetter while working for Boeing in Wichita, Kansas,[68] the field is dominated by individuals and groups that

65. Resignation Approval Letter to David Evans, December 12, 1972, Box 18, Folder 12, Coll. 0199, James C. Fletcher Presidential Records, 1937–1971, University of Utah.

66. This language of "othering" is here used primarily within the context of the history of computing, although I acknowledge its significance to a much broader set of discourses, particularly in critical race studies and gender studies, where authors such as Edward Said (1978) and Simone de Beauvoir (1949)—among many others—have discussed the myriad ways in which populations and individuals are politically, socially, culturally, and economically othered in their difference. This same discourse could be applied to the many ways in which Utah marks an "othered" space in the history of technology, namely its rural setting, its foundational fantasies of manifest destiny, and the strong presence of Mormonism as both a religion and a culture during this period.

67. B. F. Laposky. 1969. Oscillons: Electronic abstractions. *Leonardo*, 2(4): 348.

68. W. Fetter. 1982. A progression of human figures simulated by computer graphics. *IEEE Comput. Graph. Applic.*, 2(9): 10.

fall outside of the narratives of research and innovation that traditionally dominate the history of computing. Likewise, the field of computer graphics itself quickly escapes any single narrative of development as it grows and evolves to suit the needs of a wide range of disciplines and interests. Fields as diverse as computer animation, digital gaming, graphical interfaces, computer-aided-design, 3D printing, word processing, desktop publishing, data visualization, graphic design, architecture, biology, and medicine have been shaped by computer graphics over the past 50 years, and have adapted graphics in various ways to serve their own unique needs for man-machine communication. Over the course of its history, computer graphics has grown to become a medium much larger than those few key problems that Evans and others set out to solve in 1966, and as such it is crucial that we continue to attend to its history.