The Sketchpad Window

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ABSTRACT

For the first two decades of their history, computers were text only. With the exception of a few experimental military systems, they did not feature any interactive graphics displays. Then, in the 1960's, while designing the first interactive graphical computer aided design system, a young American electrical engineer named Ivan Edward Sutherland created the framework for modern computer graphics. The system was called Sketchpad, and it was created in a facility dedicated to developing and expanding the United States' defense system after the end of World War Two. Initially, however, Sketchpad was not designed for military purposes. It was the product of a culture of experimentation with the 'new' technology of the computer, and proceeded from an attempt to not only utilize the computer, but also to communicate with it. Sutherland never claimed to have a vision for the future of computer science, or for the influence that Sketchpad may subsequently have had within the development of computer graphics. While he proposed varied applications for the use of Sketchpad, Sutherland never considered the program in relation to the wider context of architectural studies. Unlike traditional architectural drawing tools that realize architectural imagination through line drawing, computer-aided architectural design programs began to use line drawing to also establish communication with the computer. Sketchpad and the computer-aided architectural design programs that evolved from it helped to facilitate the growing symbiotic relationship between the architect and the computer. Through the new field of computer drawing, the drafter began to be able to 'converse' with the computer, and crucially, through the Sketchpad window, it began to seem as if the drafter was speaking face-to-face with another person. Sketchpad's window employed the same cathode-ray tube monitor developed for television in the 1940's, and was used to illustrate a winking girl that Sutherland identified in his dissertation as 'Nefertiti'. Sutherland's 'Nefertiti' winked at him from the other side of the computer window, and seemingly came alive under his touch. Through Sketchpad's window, 'Nefertiti' effectively suggested that this new machine – the computer – was an active partner in the design process.

Dedication

This dissertation is dedicated to my children, Elyas and Ayoub.

Acknowledgements

I would like to thank my PhD advisor, Professor Paul Emmons, for supporting me throughout this journey. He patiently provided guidance and insightful discussions about the research. The theoretical knowledge I gained from Paul about architectural drawing has shaped many of the ideas I have sought to develop in my dissertation. I hope that I can one day be as knowledgeable, enthusiastic and charismatic as Paul, and to someday be able to command a classroom as well as he does.

I would also like to thank the members of my PhD committee, Professors Marcia Feuerstein, Hilary Bryon, and Jaan Holt for their helpful suggestions and critical comments that have helped me to establish the direction of this research and move forward with the investigation in more depth.

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Finally, I would like to thank my family. My husband, parents, and siblings have supported me and given me unconditional encouragement throughout. I would not have been able to complete this PhD without them.

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Introduction

This dissertation attempts to take a closer look at the invention of the first interactive computer-aided design system, called Sketchpad.[1] The purpose of this investigation is to determine Sketchpad's suitability for architectural design and drafting. A thorough examination of Sketchpad may help to reveal important aspects of current computer-aided design programs because, as the dissertation will show, those programs, and in particular, computer-aided architectural design programs, evolved from Sketchpad.[2] As a result, current computer-aided architectural design programs used by architects in the twenty-first century inherited the concepts and methods belonging to the basis for Sketchpad development.

Sketchpad was first introduced to the architectural community in 1964,[3] and went beyond being merely a new tool for architectural drawing. It was introduced by a founder of the computer-aided design group and an influential figure in the development of Sketchpad, Professor Steven A. Coons, and became a new partner in the design process.[4]

Ivan E. Sutherland, who invented Sketchpad, did not deliberately create a computer system to service architects, but as this dissertation will reveal, Sketchpad shared many characteristics with architectural drawing tools that inspired many engineers and architects to use computers in architectural practices.

While many engineers and architects believe that computers are invaluable tools for architects, some engineers and architects do not share this belief. Those who believed that Sketchpad was appropriate for architectural design and drafting thought so because of the outward similarities between traditional architectural drawing and computer drawing that included the use of freehand sketching, perspective drawing and the drawing layout of descriptive geometry. However, those who rejected the idea of using Sketchpad in architectural

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[1] Ivan Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*" (Massachusetts Institute of
[2] M. Mitchell Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*(Viking Penguin, 2001), 256. See also: *Andries van Dam, "The Shape of Things to Come*," *SIGGRAPH Comput. Graph.* 32, No. 1 (1998), 42. See also: C. Kay Alan, "The Early History of Smalltalk," in *History of Programming Languages* ed. Thomas J. Bergin, Jr. and Richard G. Gibson, Jr. (ACM, 1996), 512.
[3] Boston Architectural Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts* (Boston Architectural Center, 1964), Preface V.
[4] Ibid, 26.

design and drafting looked beyond the computer's outward similarities that alluded to traditional architectural drawing and understood that this new drawing tool gave the illusion of traditional methods, but was in fact a whole new system of drawing that offered no significant benefits to tempt architects to abandon traditional methods and replace them with the computer.

As this dissertation will reveal, those who did not approve of the use of computers in architectural drawing and design did so because of the perceived incompatibility between the computer's internal logical system and the human being's imaginative thinking, the loss of the tacit aspect of traditional architectural drawing when using Sketchpad, and the architect's posture when drawing on Sketchpad's vertical televisual monitor, which, in their opinion, prevented the architect from truly inhabiting the architectural space of the drawing.

Chapter One: The Machine, and the Rise of the Computer

This chapter examines the evolution of the machine into the computer, and the profound impact of incorporating the televisual monitor into the computer. The development of computers with monitors engendered the improvement of methods of communication with the computer.[5] Because of the television monitor, the human user perceived that the computer had the power to look back at the user through the window.[6] Drawing was the chosen method for conversing with the computer, and the drawing took place on the computer's rectangular monitor. However, drawing on a rectangular window is a tradition that has its roots in the Renaissance device of perspective.[7] While traditional drawing tools invented in the Renaissance aided the human user in the drawing process, computer scientists looked toward the act of drawing less as an end in itself, and more as a means of communication with the computer.

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[5] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*, 113.
[6] Matthew Geller, *From Receiver to Remote Control: The TV Set* (New York: New Museum of Contemporary Art, 1990), 12.
[7] David C. Lindberg, *Theories of Vision from Al-Kindi to Kepler* (Chicago: University of Chicago Press, 1981), 149. See also: Alberto Perez Gomez and Louise Pelletier, *Architectural Representation and the Perspective Hinge* (Cambridge, Mass.: MIT Press, 1997), 25. See also: Hubert Damisch, *The Origin of Perspective*, trans. John Goodman (Cambridge MIT Press, 1995), 61.

Chapter Two: The Sketchpad Invention

This chapter introduces the invention of the first interactive computer-aided design system, called Sketchpad, and the American electrical engineer Ivan E. Sutherland who invented it as part of his doctoral degree dissertation in electrical engineering, submitted to the Massachusetts Institute of Technology in January 1963.[8] The Sketchpad invention was a product of the development of the human-computer symbiosis concept, introduced in 1960 by computer scientist and psychologist J. C. R. Licklider.[9] In addition to the invention of the two-dimensional version of Sketchpad, Sutherland was also involved in the development of the three-dimensional version of Sketchpad through collaboration with his fellow colleagues and professors at Massachusetts Institute of Technology in May 1963.[10]

Chapter Three: Sketchpad, the New Partner in Design

This chapter discusses the conflicting points of view between computer scientists and philosophers on the appropriateness of using Sketchpad for tasks traditionally performed by human beings. It will reveal that the computer-aided design group at MIT failed to appreciate the qualitative nature of tacit knowing, and believed that success in programming the computer to perform human activities meant that all aspects of human intelligence would eventually be computer programmable.[11] As the chapter will reveal, philosophers and theorists argued that digital computers were limited not so much by being mindless, as by having no body. However, through Sketchpad's monitor, MIT's computer scientists suggested that the human user would be able to visualize and interact with the computer and collaborate with it as if it were a living organism that could be seen through the computer's window.[12]

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[8] *Sutherland, "Sketchpad: A Man-Machine Graphical Communication System*."

[9] J. C. R. Licklider, "*Man-Computer Symbiosis*," *IEEE Annals of the History of Computing* 14, no. 1 (1992).

[10] Timothy E. Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*" (Massachusetts Institute of Technology, 1963), 5.

[11] Hubert L. Dreyfus, *What Computer's Can't Do: A Critique of Artificial Reason* (New York: Harper and Row, 1972), 192.

[12] J.C.R. Licklider article "*Man-Computer Symbiosis*." Included in Professional Group on Human Factors in Electronics Institute of Radio Engineers, "Ire Transactions on Human Factors in Electronics," *IRE transactions on human factors in electronics.* (1960), 4.

Chapter Four: Sketchpad and Architecture

This chapter describes the introduction of Sketchpad to the architectural community through a conference entitled *Architecture and the Computer* held at the Boston Architectural Center in Massachusetts in 1964.[13] Many architects who attended this conference concluded that Sketchpad and computer graphics posed a great threat to the architect's traditional role. Architects such as Walter Gropius and Christopher Alexander were skeptical about the symbiotic relationship that architects would have with Sketchpad.[14] On the other hand, engineers such as Steven Coons and J. C. R. Licklider elaborated on the many advantages of integrating computers into architectural practices and believed that architects like engineers should take advantage of the symbiotic partnership with Sketchpad.[15]

Chapter Five: Sketchpad's Winking Face

This chapter investigates the relationship between the human user and the computer in the Sketchpad system. The partnership between two different organisms, human and computer, in the Sketchpad system was made possible through the computer's televisual cathode ray tube monitor. As the chapter will reveal, the consequences of this partnership were that the human user became increasingly dependent on the computer in the drawing process, thereby giving up an important role in the development of drawing. The chapter investigates the drawing of Winking Girl (Nefertiti) that Sutherland drew using Sketchpad, and included in his dissertation.[16] I will argue that Sutherland's drawing of Winking Girl reflects a cultural distrust of the machine industry and is communicated to others through the use of an iconic female figure in American television.

[13] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts,* Preface V.
[14] Ibid, 26.
[15] Ibid, 53.
[16] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 132.

Chapter Six: Freehand Sketching in Sketchpad

This chapter describes the strategy of using freehand sketching in Sketchpad in order to make it appealing to potential human users. Freehand sketching offered an easy way to interact with the computer without having to acquire any special skills in drawing, and the ability to create drawings without learning how to write computer algorithms. Furthermore, the chapter elaborates on the advantages from the point of view of computer scientists on the use of freehand sketches to communicate design concepts with the computer. This chapter also elaborates on the disadvantages from the point of view of architects of replacing traditional drawing tools with the computer in the making of drawings. In order to create drawings on Sketchpad's window, Sutherland had to invent a new line drawing that he described in his dissertation as a *rubber-band line.*[17] As the chapter will show, the new computer line subsequently drawn using electrical tools, including the light pen, the Lincoln Wand and the mouse, eliminated many fundamental aspects of the traditional process of making architectural drawings.

Chapter Seven: Sketchpad Expands into the Third Dimension

This chapter describes the expansion of Sutherland's two-dimensional Sketchpad program into the third dimension. The three-dimensional version of Sketchpad was called Sketchpad III and was the product of collaborative efforts between Sutherland and his colleagues at MIT,[18] the doctoral degree graduate student Lawrence G. Roberts[19] and the master degree graduate student Timothy E. Johnson, under the supervision of their professor at MIT, Steven Coons.[20] The chapter describes Roberts' process for developing the perspective-generating algorithms for his computer program,[21] and the influence that the psychologist James J. Gibson had on Roberts' work.[22] As the chapter will show, Gibson's concepts on space perception influenced the development of Sketchpad's representations. Evidence of this influence can be found in

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[17] Ibid, 18.
[18] Steven A. Coons, "*Computer-Aided Design*," *Design Quarterly*, no. 66/67 (1966), 11.
[19] *Lawrence G. Roberts, "Machine Perception of Three-Dimensional Solids*" (Massachusetts Instiued of Technology, 1963), 185.
[20] *Johnson, "Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*."353
[21] Roberts, "*Machine Perception of Three-Dimensional Solids*."159.
[22] Ibid, 161.

Sutherland's description of Sketchpad's potential representations, particularly the example of creating affordances for Alice in the computer's mathematical Wonderland.[23]

Chapter Eight: Sketchpad and the Game

This chapter reveals that Sutherland's Sketchpad idea was sourced from a game he played with as a child called the Richter Blocks toy set.[24] Many influential architects, such as Le Corbusier,[25] Bruno Taut,[26] and Frank Lloyd Wright,[27] relied on toy blocks in the conception of architectural designs. As the chapter will illustrate, the influence toy blocks had on the development of Sketchpad resulted in the creation of a computer drawing system that appealed to architects. In Sketchpad, play is performed on two levels: first, between the human and the computer through the symbiotic relationship that both entities actively participate in, and second, in the game space that the human user creates in the computer space and that can be viewed through the televisual monitor.

Chapter Nine: Sketchpad and Descriptive Geometry

This chapter describes the drawing layout of Sketchpad III. As the chapter will show, the engineers developing the Sketchpad III program chose to adopt the third-angle projection system of descriptive geometry because it was a familiar drawing layout used by draftsmen in the United States.[28] Sketchpad's descriptive geometry layout appealed to architects because it was the preferred architectural drawing convention used at the time of the Sketchpad invention. Through Sketchpad, the descriptive geometry drawing process transferred from the horizontal drafting table to the vertical computer monitor. As the chapter will reveal, replacing the traditional horizontal drafting table with the vertical computer monitor eliminated important components of

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[23] Ivan Sutherland, "*The Ultimate Display*" (paper presented at the Proceedings of IFIP Congress, 1965).
[24] Ivan E. Sutherland, *Odysseys in Technology: Research and Fun* (Mountain View, CA, US: Computer History Museum, 2005).
[25] Paul Emmons, John Hendrix, and Jane Lomholt, *The Cultural Role of Architecture: Contemporary and Historical Perspectives* (Milton Park, Abingdon, Oxon; New York, NY: Routledge, 2012), 132.
[26] Juliet Kinchin and Aidan O'Connor, *Century of the Child: Growing by Design, 1900-2000* (Museum of Modern Art, 2012), 61.
[27] Pat Bruce Tina Froebel Blockplay Research Group Gura, *Exploring Learning: Young Children and Blockplay* (London: P. Chapman Pub., 1992), 10.
[28] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." 19.

traditional architectural drawing practices.[29] The purpose of using the descriptive geometry layout in Sketchpad III was to rely on the computer in constructing parts of the drawing that could be generated by computer program.[30]

Chapter Ten: Sketchpad and the Industry

This chapter describes the development of computer-aided architectural design programs that evolved from Sketchpad. Initially, architects' hesitated in incorporating the computer into architectural practices. As a result, architects lost an opportunity for leadership in the computer industry and had to use computer-aided design programs that were developed for the building industry.[31] As the chapter will reveal, with the establishment of *software copyright* in 1974, it became difficult to alter existing computer programs to accommodate architectural uses.[32] Consequently, J. C. R. Licklider believed this focus upon the commercial value of computer programs resulted in a situation where the wealthy segment increasingly dominated and controlled the computer industry, and shaped it to serve their own needs.[33]

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[29] Paul Emmons, "*Back to the Drawing Board: Embodiment in Architectural Drawing Practices*." 9.
[30] Coons, "*Computer-Aided Design*." 9.
[31] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 1.
[32] Michael D. Scott, *Scott on Information Technology Law* (Aspen Publishers, 2007), 18.
[33] J. C. R. Licklider, "*Some Reflections on Early History*," in *Proceedings of the ACM Conference on The history of personal workstations* (Palo Alto, California, USA: ACM, 1986), 124.

Figure 1: The Sketchpad Window dissertation frontispiece. (Drawn by the author)

Chapter One: The Machine, and the Rise of the Computer

Any study of machine and computer evolution can be approached according to two essentially different modes of thought. The first mode may be described as the 'engineering approach', which is mostly concerned with technical fact. The second can be described as the 'social approach', which views technology in terms of its connections with humanity, and investigates the machine in relation both to human labor, and as a social artifact.[34] This dissertation is concerned with the latter approach. In this approach, machines are not viewed simply as being an extension of the human body. On the contrary, the human being becomes a user within a computer-aided design system.[35] In that system, human attributes are filtered according to the capabilities of the computer and limited to attributes that can be conveyed to and from the computer.

Two influential figures of the many that explored the early definitions of machines in the twentieth century were the mechanical engineer Franz Reuleaux and the philosopher of technology Lewis Mumford.[36] Reuleaux was a pioneer in the field of kinematics, and was influenced by the study of the science of mechanism in his own definition of 'the machine'. Reuleaux defined the machine as: "a combination of resistant bodies so arranged that by their means the mechanical forces of nature could be compelled to do work."[37] And while Mumford quoted Reuleaux's definition of the machine in his book entitled *Technics and Civilization*, published in 1934,[38] Mumford believed that Reuleaux's definition of the machine ignored the human role in operating that machine, and effectively ignored its historical development as a tool for human use, noting that Reuleaux's definition "leaves out the large class of machines operated by man-power."[39]

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[34] Harry Braverman, *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century* (Monthly Review Press, 1998), 127.
[35] J.D. North, "*The rational behavior of mechanically extended man*" (September, 1954), cited in Licklider, "Man-Computer Symbiosis" p. 2.
[36] Branden Hookway, *Interface* (Cambridge, Massachusetts The MIT Press, 2014), 41.
[37] Franz Reuleaux, *Kinematics of Machinery: Outlines of a Theory of Machines* (Dover Publications, Incorporated, 2012), 35.
[38] Lewis Mumford, *Technics and Civilization* (University of Chicago Press, 2010), 9.
[39] Ibid, 9.

Mumford proceeds from a human-centered perspective, arguing that the use of machines is limited in comparison to the wider range of free action that traditional tools offer to the human user. For Mumford, the machine represented a narrowing of possibilities of use, when compared to traditional tools. As he stated: "The essential distinction between a machine and a tool lies in the degree of independence in the operation from the skill and motive power of the operator: the tool lends itself to manipulation, the machine to automatic action."[40]

Mumford's ideas were very close to those of Reuleaux, especially in his description of the particular changes wrought by the machine upon human values, aesthetics and ethics. The major difference, however, between Mumford and Reuleaux occurs in their conclusions as to the particular influence of the machine with regards to the notion of "societal value." Reuleaux posits an optimistic view as to the many possibilities that the machine offers to society, especially through industrial automation, while Mumford takes a more pessimistic position, viewing the role of the machine and its operation within the industrial system as the "modern agent of social evil."[41] Francis C. Moon, professor of mechanical and aerospace engineering at Cornell University speculates as follows as to the differences between Mumford and Reuleaux's conclusions:

> Perhaps it is the nature of the engineer to be an optimist. Engineers have always been taught to solve problems and the possibilities of the machine allow many options for the engineer to address society's physical problem. The social historian has only the power of words and persuasion; and sometimes in the face of social unrest and insecurity … pessimism is the natural outlook.[42]

Size, complexity, or speed of operation aside, one key element common to the evolution of both the machine and the computer is the manner in which its operations are controlled.[43] The concept of *man-computer symbiosis* is different to the concept of *mechanically extended man* that is associated with man-machine systems. In his paper *Man-Computer Symbiosis*, the computer scientist and psychologist J.C.R. Licklider argued that this concept differed from the concept of

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[40] Ibid, 10.
[41] Francis C. Moon, *The Machines of Leonardo Da Vinci and Franz Reuleaux: Kinematics of Machines from the Renaissance to the 20th Century* (Springer Netherlands, 2007), 237.
[42] Ibid, 237.
[43] Braverman, *Labor and Monopoly Capital: The Degradation of Work in the Twentieth Century*, 129.

“humanly extended machines.” While the computer is both a machine ***and*** an automatic system that can replace man in automatic processes, Licklider maintained that a human had to be part of the system.[44] Licklider goes on to expand this notion, stating that:

> In the man-machine systems of the past, the human operator supplied the initiative, the direction, the integration, and the criterion. The mechanical parts of the systems were mere extensions, first of the human arm, then of the human eye. These systems certainly did not consist of dissimilar organisms living together. There was only one kind of organism - man, and the rest was there only to help him.[45]

Computer Intelligence

The integration of the human user within the computer aided design system emerged as a form of communication between humans and computing machines. This communication was made possible through the computer’s interface, and the elements that are positioned upon that interface can be said to be 'human' in as much as the zone defined by the interface extends into the domain of the human user and the machine. This relational positioning of elements between human and machine can be described as *intelligence*.[46] Intelligence in this context describes activities brought into being and made possible through this relation with the interface. The primary function of the interface is to offer control, and the means for achieving this control is intelligence.[47] Intelligence is a quality of both encounter and measure; “The human-machine interface is neither fully human nor fully machine; rather, it separates human and the machine, while defining the terms of their encounter.”[48]

The cultural theorist Branden Hookway believed that intelligence was concomitant with the Roman God Genius, who was believed to encompass and inform the whole human experience, simultaneously created and creating.[49] The notion of Genius was believed to exist at locations as diverse as gates, baths and market places, enabling these places to produce their own

[44] J. C. R. Licklider, *"Man-Computer Symbiosis,"* *IEEE Annals of the History of Computing* 14, no. 1 (1992).
[45] Ibid.
[46] Hookway, *Interface*, 43.
[47] Ibid, 44.
[48] Hookway, *Interface*, 44.
[49] Ibid, 121.

Genii.[50] Here, Genius extends from persons to things and places and, like intelligence, describes an encounter between a human being and non-human forms such as the machine. Here, in this man-computer symbiosis, intelligence enables effective connections between the human and the machine. Hookway argues that the genius of augmentation in the interface corresponds with the *ingenium* described by eighteenth-century philosopher Giambattista Vico.[51]

For Vico, *ingenium* connects many diverse things, but primarily enables a person to recognize likeness, and then create an approximation of that himself. Vico's characterization of human reason and thought makes a separation of mind and body impossible. Therefore, *ingenium* is an embodied intelligence; one that Vico termed "mother wit," and it is literally 'birthed' into a human being. Vico goes on to add that human ingenium gives birth to mechanics in a manner similar to the way in which nature generates physical things. Vico stated: "Ingenium is the faculty that connects disparate and diverse things… just as nature generates physical things, so human ingenium gives birth to mechanics, and as God is nature's artificer, so man is the god of artifacts?"[52]

Prior to the invention of computer-aided design, early computers performed the limited tasks of numerical calculations and could only provide answers to predetermined questions in the form of stacks of punch cards that were fed to the computer by an operator. Later, these computers were enhanced through programming to handle non-numerical information.

The term *computer* originated as a description of individuals who performed the cumbersome task of mathematical calculations, and were consequently known as "human computers."[53] The distinction between the machine and the computer has been debated amongst pioneers in the field of computer science and engineering from the earliest days of the invention of the computer. During the early 1940's computing machines were typically called *calculators*, and the term *computer* was generally applied to people.[54] In the early nineteenth century the mathematician Charles Babbage invented the first mechanical-computer to replace the human-

[50] Ibid, 121.
[51] Ibid, 122.
[52] Giambattista Vico, *De Antiquissima Italorum Sapientia Ex Linguae Latinae Originibus Eruenda*, trans. Lucia M. Palmer (Cornell University Press, 1988), 97.
[53] Jeremy M. Norman, *From Gutenberg to the Internet: A Sourcebook on the History of Information Technology* (Novato: Historyofscience.com, 2005), 107.
[54] Ibid, 107.

computer and referred to his machine as the *calculating engine*, *Difference Engine* or *Analytical Engine*.[55] Babbage's machines relied on receiving input data in the form of numerics, a process informed by the first computer program written by his assistant Ada Lovelace.[56]

Indeed, the role of women in the development of computers has been significant, from the development of computer software through to hardware.[57] And yet, although both female gender and the distribution of power between men and women has influenced the nature of the relationship that inventors have developed with their computers,[58] not enough recognition has been given to the vital role played by women in the advancement of computer technology.[59] For instance, six women mathematicians, "known as human computers," created working programs for the first general-purpose electronic computer called ENIAC in the United States,[60] during the Second World War.[61]

The machines built by the pioneers of computing in the 1940s were known as *electronic brains*. However, the word *computer* began to take over in modern speech because, in their earliest forms, those 'brain machines' were unable to perform any task beyond numerical calculation. Computers were later programmed for handling non-numerical information, but remained for the most part dealing with certain facts.[62]

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[55] Neil Champion and Charles Babbage, *Charles Babbage* (Chicago, Ill.: Heinemann Library, 2001), 18.
[56] Ada, Countess of Lovelace and daughter of poet Lord Byron, is considered as the first computer programmer. Linda Null and Julia Lobur, *The Essentials of Computer Organization and Architecture, Fourth Edition* (Burlington, MA: Jones & Bartlett Learning, 2015), 20.
[57] Janet Abbate, *Recoding Gender: Women's Changing Participation in Computing* (Cambridge, MA: MIT Press, 2012), 2.
[58] Ibid, 3.
[59] Veena Rao, *Advanced Radiant Readers* (New Delhi: Allied Publishers, 2008), 163.
[60] Alice R. Burks and Arthur W. Burks, *The First Electronic Computer* (Michigan: University of Michigan Press, 1988), 1.
[61] Thomas J. Misa, *Gender Codes* (New Jersey: John Wiley & Sons, 2010), 3.
[62] Donald J. Michie, *The Creative Computer: Machine Intelligence and Human Knowledge* (New York: Viking, 1984), 34.

Computers without Windows

The introduction of the computer window is synonymous with the introduction and development of cathode ray tubes in the United States. Earlier computers that did not have windows made it impossible to utilize line drawing as input data. Given this, however, the concept of human-machine intellectual interaction can actually be traced back as early as the 1920s, as it was present in the early teaching machines built by the computer scientist and educational psychologist Sidney Pressey.[63] His machine resembled a typewriter with a window that presented a question to the pupil and offered four possible answers. (See Figure 2) The pupil would press a key on the typewriter to indicate his selected answer, and if the answer presented was correct, the machine would provide the pupil with the next question. If the answer proved to be incorrect, the pupil would carry on selecting other answers until he chose the right one.[64] Pressey's teaching machines provided a salient and immediate reinforcement of an understanding and communication between the human and the computer.

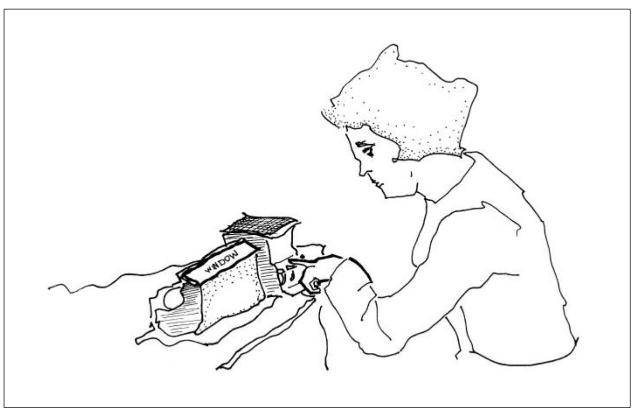

Figure 2: Drawing of Sidney Pressey's Teaching Machine (Drawn by the author)

[63] William J. Mitchell, *Computer-Aided Architectural Design* (New York: Van Nostrand Reinhold, 1977), 11.
[64] Jamandlamudi Bhaskara Rao Digumarti Prasanth Kumar, *Methods of Teaching Civics* (New Delhi: Discovery Pub. House, 2004), 135.

Licklider described the slow form of communicating with the computer through punch cards as being similar to the slow process of communicating with another person by writing and mailing letters. His education in physiological psychology gave him the ability to make connections between human beings and computer technology, and as an experimental psychologist, Licklider found that the human capacity to perceive, make choices and devise new ways to tackle problems equally "as worthy of respect" as a computer's ability to execute algorithms.[65] Licklider certainly believed that the brain was a system of immense complexity, but nonetheless, it was a system – not so different in its fundamentals from the electronics systems that engineers built in their laboratories.[66]

Licklider believed that the successful creation of a productive computer system relied upon the ability of the human user to communicate with ease with that computer. Within these interactions, the human user's communications with the computer was like corresponding with another person through a letter. After the punch cards were written, there was a waiting period before receiving a response from the computer. Essentially, the human operator was like a postman delivering mail back and forth between the user and the computer. Licklider believed that both human and computer should have a 'conversation' rather than a 'correspondence', and as a result, both would become more productive through such a 'conversation'.

The potential advantages of this human-machine dialogue for problem solving were classically formulated in Licklider's paper *Man-Computer Symbiosis,* where he stated:

> Many problems that can be thought through in advance are very difficult to think through in advance. They would be easier to solve, and they could be solved faster, through an intuitively guided trial-and-error procedure in which the computer cooperated, turning up flaws in the reasoning or revealing unexpected turns in the solution. Other problems simply cannot be formulated by computing-machine aid. Poincare anticipated the frustration of an important group of would-be computer users when he said, 'The question is not, what is the answer? The question is, 'What is the question?' One of the main aims of man-computer symbiosis is to bring the computing machine effectively into the formulative parts of technical problems.[67]

[65] M. Mitchell Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal* (Viking Penguin, 2001), 12.
[66] This was a shared belief among physiological psychologists in the twentieth century. Ibid, 12.
[67] Professional Group on Human Factors in Electronics Institute of Radio Engineers, "Ire Transactions on Human Factors in Electronics," *IRE transactions on human factors in electronics.* (1960), 5.

Licklider believed that this form of communication between the human user and the computer would enhance the extent of effective utilization of the power of the computer. The more easily the human user could communicate ideas to the computer, the more the human user would benefit from the capabilities of the computer. His objective was to adapt computers to humans who used them for the sake of exploiting the strengths of each.[68] Licklider believed that "one-way communication is good", but that "two-way communication" in "man-computer interaction is better."[69]

The advantages of a symbiotic relationship between human and computer could be further understood from the following excerpt from Licklider's paper *Man-Computer Symbiosis*, where he stated: "In the anticipated symbiotic partnership men will set the goals, formulate the hypothesis, determine the criteria, and perform the evaluations. Computing machines will do the routine work that must be done to prepare the way for insights and decisions in technical and scientific thinking."[70]

Computers with Windows

In the mid-1960s, Licklider was asked to write an appendix for the Carnegie Commission report on the future of television, and in this appendix he described the concepts of *man-computer symbiosis* and *narrowcasting* that were destined to converge in the 1990s to create the current state of interactive computer graphics that is widely spread through personal computers.[71]

With the development of computers possessing windows came the idea of using line drawing to communicate with the computer. These first windows were called *cathode ray tubes*, or CRTs, and were the same ordinary television picture tubes used in households in the United States.[72] The cathode ray tube was developed by scientists for the purpose of indicating and measuring a variety of phenomena via an inertia-free electron beam. Because of this freedom

[68] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*, 12.
[69] J. C. R. Licklider, "*A Picture Is Worth a Thousand Words: And It Costs*," in *Proceedings of the May 14-16, 1969, spring joint computer conference* (Boston, Massachusetts: ACM, 1969), 619.
[70] *"Man-Computer Symbiosis*." 4.
[71] Nicholas Negroponte, *Being Digital* (New York, NY: Vintage Books, 1996).
[72] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*, 113.

from inertia, the CRT is capable of responding to voltage variations over frequency ranges at rapid speeds. The electron beam is directed against a fluorescent screen, and the human perceiver watching the screen observes the voltage variations in the form of a moving spot of light.[73] As a result, the CRT was used to provide visual data on variations of natural phenomena such as light, heat, sound, and mechanical motion so long as these phenomena were converted into equivalent voltages.[74]

The history of the development of the CRT as a useful medium in the field of computer science effectively began with America's entry into World War II. That war changed the focus from developing television as a medium for recreational purposes into technology that could also serve military needs. Consequently, the knowledge gained in developing the CRT for television was fundamental in the development of radar during World War II.[75] Radar, like television, presents information in the form of spots of light on the CRT screen. In a radar system, each spot of light represents the reflection of a transmitted radio wave that has struck an object within the range of the radar system.[76] The Japanese attack on Pearl Harbor in 1941 put a halt to much television programming in the United States. Many American television stations reduced their schedules to approximately four hours a week, or went off the air completely. The American electrical industry gradually converted to total war production.[77] And after the war, the development of the CRT became essential to the development of the computer monitor.

To understand the importance of the CRT and its impact on computer development, it seems helpful to gain an understanding of the history and fundamental properties of the CRT. As a medium for television-picture reproduction, the CRT effectively produced a high-definition television picture of several hundred lines per inch.[78] Television is a term that is applied to the electrical transmission of images over a distance and the simultaneous reproduction of those images instantaneously at a remote receiving point.[79] The image is made of reflected light, and

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[73] Allen B DuMont, *The Cathode-Ray Tube and Typical Applications; a Non-Technical Discussion of the Cathode-Ray Tube* (Clifton, N.J1948), 1.
[74] Ibid, 1.
[75]Ibid, 2.
[76] DuMont, *The Cathode-Ray Tube and Typical Applications; a Non-Technical Discussion of the Cathode-Ray Tube*, 2.
[77] Albert Abramson, *The History of Television, 1942 to 2000* (Jefferson, N.C.: McFarland, 2003), 3.
[78] DuMont, *The Cathode-Ray Tube and Typical Applications; a Non-Technical Discussion of the Cathode-Ray Tube*, 1.
[79] Ibid, 51.

the meaning of the image is determined by the geometrical arrangement of the light creating that creates it. When it is converted into electrical voltage, the entire image is presented at once in a method called scanning.[80] The device used to scan the picture and convert it into successive electrical impulses is called an iconoscope. The iconoscope generates and directs an electron beam at a photosensitive plate called a mosaic. The mosaic records the amount of light striking it and stores that information in electrical charges distributed over its surface. The complete image information is contained in the mosaic, similar to the complete picture information contained on a film when the camera lens is opened.[81]

Prior to the military's interest in the CRT, refinements to that technology continued at facilities interested in television research that focused on improving screen display by increasing picture contrast. By 1935, most CRTs had a circular screen with a diameter that measured from three to five inches. Researchers in the field of television soon became aware of the desirability of larger pictures for viewing by more than one or two people, which led to the development of larger screens.[82]

Commercial television receivers were introduced in the United States at the 1939 New York's World's Fair, which marked the beginning of regular television broadcasting in the United States.[83] The Professor of Media and Communication Gary Edgerton stated: "No technology before television ever integrated faster into American life."[84] Television took approximately ten years to reach thirty-five million households in the United States, while the telephone took eighty years, the automobile fifty years, and the radio twenty-five years.[85]

In his 1967 book entitled *The Medium is the Message* the philosopher of communication theory Marshall McLuhan argued that electric technology,[86] particularly the television, reshaped

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[80] DuMont, *The Cathode-Ray Tube and Typical Applications; a Non-Technical Discussion of the Cathode-Ray Tube*, 51.
[81] Ibid, 52.
[82] Peter A. Keller, *The Cathode-Ray Tube: Technology, History, and Applications* (New York: Palisades Press, 1991), 135.
[83] Ibid, 135.
[84] Gary R. Edgerton, *The Columbia History of American Television* (New York: Columbia University Press, 2007).
[85] Ibid.
[86] According to the author's son Eric McLuhan, "The title was a mistake. When the book came back from the typesetter, it had on the cover 'Massage' as it still does. The title should have read *The Medium Is the Message* but the typesetter had made an error. When Marshall McLuhan saw the typo he exclaimed, 'Leave it alone! It's great, and right on target!' Now there are four possible readings for the last word of the title, all of them accurate: *Message*

societies and changed social aspects of contemporary life. McLuhan stated, “The environment that man creates becomes his medium for defining his role in it… Now, with TV and folk singing, thought and action are closer and social involvement is greater.”[87] Through media, particularly the television, “the extension of any one sense alters the way we think and act, the way we perceive the world.”[88]

McLuhan believed that television was a medium fundamentally different to other visual media, such as the movies.[89] Somehow, people did not look at the television screen the way they looked at a movie screen. In fact, McLuhan asserted, “In some sense the spectator is himself the [television] screen.”[90]

The influence of television was so profound that it expanded the individual’s mind and senses to reexamine his surroundings in the hope of discovering new opportunities to improve the quality of the human environment.[91] In 1935, a General Electric institutional advertisement wondered: “What is television, a gadget, or a form of entertainment? Neither. It represents another step forward in man’s mastery of time and space. It will enable us, for the first time, to see beyond the horizon.”[92]

In the household, the television occupied a vital new space in the home and was thought of as a window on the world that could never look back at the subject.[93] In early writings on the television set, magazines idealized notions of television sets as large picture windows opening onto the outside world, and even though these windows were a 'one way' view of the outside world, magazines warned that such windows had to be carefully covered with curtains or venetian blinds to protect the residents of the home from being seen.[94] Even the design of the early television consoles covered the TV screen with cabinet doors for fear of being seen by the television. This fear was effectively expressed in a 1949 *Saturday Evening Post* that read: “Be

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and *Mess Age*, *Massage* and *Mass Age*.” Kate Thomas, *Postal Pleasures: Sex, Scandal, and Victorian Letters* (USA: Oxford University Press, 2012), 132.

[87] Marshall McLuhan, *The Medium Is the Massage* (New York: Gingko Press, 1967).

[88] Ibid, 41.

[89] Philip Marchand, *Marshall Mcluhan: The Medium and the Messenger* (Cambridge: MIT Press, 1998), 132.

[90] McLuhan, *The Medium Is the Massage*, 125.

[91] Ibid, 8.

[92] Matthew Geller, *From Receiver to Remote Control: The TV Set* (New York: New Museum of Contemporary Art, 1990), 65.

[93] Ibid, 12.

[94] Geller, *From Receiver to Remote Control: The TV Set,* 12.

Good! Television's Watching! Another invasion of your privacy, TV's prying eye may well record such personal frailties as the errant husband dining with his secretary."[95]

Television brought to the home a vision of the world that the human eye alone could never see. This fascination with perfecting human vision through technology predates the period of the invention of the television and includes other machines for vision such as the telescope. Television was the ultimate expression of this technologically improved view, and was referred to as a "hypnotic eye," an "all seeing eye," a "mind's eye" and so on.[96] In a 1954 documentary produced by RCA and aired on NBC entitled *The Story of Television,* a voice-over narrated the following: "The human eye is a miraculous instrument. Perceptive, sensitive, forever tuned to the pulsating wavelength of life. Yet the eye cannot see over a hillside or beyond the haze of distance. To extend the range of human eyesight, man has developed miraculous and sensitive instruments."[97] Most remarkable among these instruments was the "electronic eye" of the television.

Outside the USA, in Europe, television monitors were developed in a different manner and had a different influence on European popular culture, particularly with relation to the medium of film. Indeed, as early as 1939, German television receivers used rectangular picture tubes that were similar in size and appearance to postwar American rectangular tubes.[98] These tubes predated American ones, which were developed a decade later. The first series of rectangular picture tubes launched in the United States in 1949 featured a 16-inch screen.[99] The rectangular picture tube rapidly displaced the round tube and by the time interactive computer design was invented,[100] all new picture tubes were rectangular.[101]

The transformation of the CRT from a circular to a rectangular screen caused a change in the shape of the computer monitor from the circular porthole to the rectangular frame. It was apparent from the early days of television that a rectangular picture displayed on a round screen

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[95] Ibid, 12.
[96] Ibid, 13.
[97] Ibid, 13.
[98] Keller, *The Cathode-Ray Tube: Technology, History, and Applications*, 157.
[99] Ibid, 157.
[100] The CRT used in the first interactive computer aided design system was a monochrome monitor and so the line drawings were white lines that were drawn on a black background. The development of color television followed the invention of the monochrome CRTs and almost completely replaced monochrome television by the 1970's. Ibid,168.
[101] Ibid,158.

was not an appropriate fit. This was because the picture was expanded to the full width of the tube, which resulted in clipping the picture corners, or the picture corners would be kept within the viewable screen area and the remainder of the screen would be concealed from the viewer, resulting in a large area of the screen being wasted.[102] Early computer displays had a circular shape, such as the Whirlwind computer that was developed at MIT's Lincoln laboratory,[103] which fully utilized the round tube in order to arrange the electrons on the screen to serve its purpose for radar.

The move in television from a circular porthole to a rectangular frame had a direct effect upon the development of the computer monitor, in that it was easier to conceptualize drawing on a rectangular screen because people were already used to drawing on rectangular paper.[104] According to the technological drawing historian Peter Booker, in his book entitled *A History of Engineering Drawing*, published in 1963: "Drawings are like windows through which we see things. The draughtsman, who is a maker of these windows, appreciates the effort put into them much more than others, who only see through drawings, as it were, to the things themselves depicted."[105]

The CRT television set of the forties and fifties was described in many early publications as a window.[106] These picture tubes were made of glass and in essence did resemble an actual window.[107] As the idea of a picture as a window was accepted, a natural way of drawing a scene

[102] Ibid, 155.
[103] The US Navy sponsored the Whirlwind project at MIT. The Whirlwind computer that was constructed under the leadership of Jay W. Forrester in 1949 occupied a two-story building with its central processing unit, control consoles, and CRT displays on the second floor. It continued operation until 1959. Today, parts of it can be found in the Smithsonian Institution in Washington, DC, and the Computer Museum History Center in Mountain View, CA. Edwin D. Reilly, *Concise Encyclopedia of Computer Science* (Chichester: Wiley, 2004), 793.
[104] It is likely that the reason we use rectangular paper goes back to the origins of paper production. There is a long history of papermaking and various materials that were used to make paper. In the early nineteenth century, papermakers made paper by hand through a process of dipping a mold into a large vat containing beaten pulp in suspension. Papermakers found it easier to control rectangular molds than square ones. The rectangular paper tradition continued after the process was mechanized in the late nineteenth century, and mechanized blades were used to cut the rolls of paper. Tradition has kept the shape of paper rectangular. Andrew E. Samuel, *Make and Test Projects in Engineering Design Creativity, Engagement an Learning* (London: Springer, 2006), 87.
[105] Peter J. Booker, *A History of Engineering Drawing* (London: Chatto & Windus, 1963).
[106] Geller, *From Receiver to Remote Control: The TV Set*, 12.
[107] John Kitzmiller, *Television Picture Tubes and Other Cathode-Ray Tubes: Industry and Trade Summary* (Darby: Diane Publishing Company, 1995), 4.

became apparent.[108] The development of this drawing system can be traced back to the Renaissance architect Leon Battista Alberti's perspective device.[109]

Alberti[110] was the first author to write a treatise on drawing perspective using hardware with a vertically framed window.[111] Alberti's *Della pittura* translated as *On Painting*, written in 1435, gave theoretical expression to the perspective techniques invented by the Florentine architect Filippo Brunelleschi and demonstrated by him in an experiment.[112] Brunelleschi's interactive experiment allowed observers to compare the octagonal baptistery in Florence's Piazza San Giovanni with a perspective painting of the building that he made to verify the correctness of the representation.[113] The experiment required that the observer view the octagonal baptistery from the threshold of the Duomo. The observer looked through a hole in a rectangular wooden panel of a painting of the baptistery that Brunelleschi had painted. However, the observer looked at a reflection of the painting and not the painting itself.[114] Moreover, in a perspective painting, the painter determines a fixed point from which the painting must be seen;

108 Booker, *A History of Engineering Drawing*, 23.
109 Mario Carpo and Frederique Lemerle, *Perspective, Projections and Design: Technologies of Architectural Representation* (London: Routledge Taylor & Francis Group, 2013), 53.
110 Alberti was a Renaissance humanist, theorist, engineer, poet, mathematician, and architect. Born into a Florentine family in Genoa in 1404, he was sent to a boarding school in Padua, where he received a classical Latin education, then earned a degree in canon law from the University of Bologna. He served as secretary to the Papal Chancery in Rome, a position that assured him of a source of income. In 1435, he returned to Florence, where his close association with the architect Brunelleschi influenced him. Leon Battista Alberti, *On Painting*, trans. Cecil Grayson and Martin Kemp (London: Penguin Books, 2004), 1.
111 David C. Lindberg, *Theories of Vision from Al-Kindi to Kepler* (Chicago: University of Chicago Press, 1981), 149. See also: Alberto Perez Gomez and Louise Pelletier, *Architectural Representation and the Perspective Hinge* (Cambridge, Mass.: MIT Press, 1997), 25. See also: Hubert Damisch, *The Origin of Perspective*, trans. John Goodman (Cambridge MIT Press, 1995), 61.
112 Filippo Brunelleschi was a native Florentine architect who lived from 1377 until 1446. He was originally trained as a goldsmith but excelled in many other arts. He built many important classical works of the early Renaissance, but it was the dome he constructed for the Florence cathedral that earned him a reputation as the only fifteenth-century Italian architect capable of engineering that dome. Harry Francis Mallgrave, *Architectural Theory. 1, an Anthology from Vitruvius to 1870* (Malden, MA: Blackwell Publ., 2009), 28.
113 Alberti, *On Painting*, 1.
114 The observer held the panel toward the baptistery, with the panel's backside facing him, in one hand; he held a mirror at arm's length in the other hand. He then placed the panel between himself and the baptistery and looked at the painting's reflection in the mirror through a viewing hole in the panel located at the vanishing point of the painting. The reflected painting on the panel would look exactly like the actual scene. Comparing the baptistery with a perspectival representation assured the observer of perspective's effectiveness as a painting technique. Furthermore, instead of painting the sky on the panel, Brunelleschi applied a reflective material, possibly because he was most interested in the geometric representation of architectural perspective—a theory less applicable to the clouds and the sky. In Antonio Manetti's documentation of Brunelleschi's work in his Vita di Brunellesch, the author reminded readers that in a perspectival painting the painter determines a fixed point from which the painting must be seen; for Brunelleschi, the viewing hole in the panel was the fixed point he determined for the viewer. His illusionistic painting succeeded remarkably in imitating nature and revolutionized the Renaissance's regard for the art of painting.

for Brunelleschi, the viewing hole in the panel was the fixed point he determined for the viewer.[115] From Brunelleschi's demonstration, the connection between perspective drawing and the window was established in the Renaissance.

Licklider recognized very early on in the development of electrical computers that focus should be made upon utilizing the computer window to enhance communication between the human user and the computer. According to Licklider, communicating with the computer through its televisual monitor was challenging because:

> Viewers do, in a sense, participate in conventional television programs. If the program material is dramatic and matched to a viewer's motivations, the viewer may sit on the edge of his chair, empathize overtly, and utter words of encouragement. That kind of participation fails, however, to qualify as interactive participation, since the actual course of a broadcast television program depends in no way upon the concurrent behavior of its viewers. The criterion for what is here called interaction is that both the program and the viewer be capable of influencing each other.[116]

Because the pencil and pad or the chalk on blackboard were very effective approaches of communicating ideas amongst engineers, Licklider believed that a possible solution to strengthen communication with the computer could be made through line drawing on the computer's display.

[115] Lindberg, *Theories of Vision from Al-Kindi to Kepler*, 149.
[116]J.C.R. Licklider, "*Televistas*," in Carnegie Commission on Educational Television, *Public Television: A Program for Action* (New York Bantam 1967), 203.

Chapter Two: The Sketchpad Invention

In the 1960's, early human-computer interaction research was built on a "legacy of leadership" from Licklider, who envisioned a future of human augmentation and symbiosis with computers. Cold War investment in technological research could fund long-term research efforts toward these ends. The large program at the Lincoln Laboratory resulted in the first GUI [graphical user interface], Sketchpad, and a primordial 3-D mouse, the Lincoln Wand."[117]

In 1962, Ivan Edward Sutherland, an American electrical engineer and graduate student at Massachusetts Institute of Technology invented the first graphical computer-aided design system and called it Sketchpad.[118] Having access to the interactive machine at MIT called the TX-2 computer gave Sutherland the idea for his doctoral dissertation entitled *Sketchpad: A Man-Machine Graphical Communication System*, which he submitted to MIT in January 1963.[119]

The Sketchpad system that was developed particularly for MIT's TX-2 computer consisted of the Sketchpad program, a screen referred to as the "page" or "scope" or "window," the light pen, push buttons, and connected to a plotter. (See Figure 3) Sketchpad enabled the human user to create line drawings directly onto the computer's monitor using a hand-held device in the shape and size of a fountain pen called the light pen.[120] Unlike other computer systems that were developed at the time, Sketchpad was unique because it allowed the human user to interact directly with the computer through a monitor.

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[117] F. Blackwell Alan, "*The Reification of Metaphor as a Design Tool*," *ACM Transactions on Computer-Human Interacttion* 13, no. 4 (2006), 496.
[118] Ivan Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*" (Massachusetts Institute of Technology, 1963).
[119] Harry Henderson, *Encyclopedia of Computer Science and Technology* (New York: Facts On File, 2009), 463.
[120] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 8.

Figure 3: Ivan Sutherland operating Sketchpad on the TX-2 Computer at MIT. Ivan Sutherland, "Sketchpad: A Man-Machine Graphical Communication System" (Massachusetts Institute of Technology, 1963), 20. (By courtesy of MIT)

Inspired by Licklider's concept of creating a symbiotic partnership with the computer using the display system, Sutherland's Sketchpad invention utilized the computer's interface and transformed the nature of communication with the computer from corresponding via numerical punch cards[121] to conversing via line drawing. "It was the first drawing program at a time when computers were thought of as giant calculators."[122] Sketchpad "demonstrated that computers could be used for drafting and modeling, not merely for number crunching."[123]

Sutherland defined the parts of the Sketchpad system and their uses, and included "the first computer drawing software"[124] that allowed the user, for the first time in history, to draw lines and circles on a computer display system; thereby making Sutherland both inventor and

[121] Batch processing allowed professional operators to combine decks of cards into batches, or bundles. The decks of punched cards were fed to the computing machine, and the computing machine would then process the data. These early operating systems reduced "idle computer time" by removing the users from the computer room. Per Brinch Hansen, *Classic Operating Systems: From Batch Processing to Distributed Systems* (New York: Springer, 2001), 4.
[122] Steve Lohr, *Go To* (New York: Basic Books, 2008), 148.
[123] Yehuda E. Kalay, *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design* (Cambridge, MA: MIT Press, 2004), Preface xiv.
[124] Henry Lieberman, Fabio Patern, and Volker Wulf, *End User Development* (New York: Springer, 2006), 18.

developer of interactive computer graphics.[125] "Sketchpad's many innovations include a display file for screen refresh, a recursively traversed hierarchical structure for modeling graphical objects, a recursive method for creating geometric transformations, and an object oriented programming style."[126] Sketchpad also had one of the "first window-drawing programs and clipping algorithms, which allowed zooming."[127] For his pioneering contributions to the field of computer graphics Sutherland was given many prestigious awards,[128] including the 1988 ACM A. M. Turing award, considered to be the highest honor in computer science research.[129]

Sutherland's Sketchpad invention was not commercially available,[130] and remained limited to his own personal use and the use of those who had access to MIT's Lincoln laboratory.[131]

Andries van Dam, an American professor of computer science at Brown University and co-founder of the *ACM Siggraph conference*, and recipient of the 1991 *Steven A. Coons Award*, described the Sketchpad system as a landmark event in the history of computer science, and that Sketchpad introduced a new field called "computer graphics" into the field of computer science through a film demonstration recorded by Sutherland. Van Dam stated: "I did my Ph.D. thesis on graphics, after having been inspired by Sutherland's landmark 1963 film on Sketchpad, and taught my first graphics class at Brown in the spring of 1966."[132] Also, as Van Dam related: "I still show the Sketchpad film in my introductory course each year and, like the old timer who tells his kids about walking ten miles to school, in the snow, barefoot, I always emphasize to my students … [Sketchpad brought a change to computers in] an era defined by batch processing with punched cards."[133]

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[125] Lev Manovich, *Software Takes Command* (New York: Bloomsbury Academic, 2013), 86.
[126] Ibid, 86.
[127] Jon Peddie, *The History of Visual Magic in Computers How Beautiful Images Are Made in Cad, 3d, Vr and Ar* (London; New York: Springer, 2013), 99.
[128] The first use of the phrase *Computer Graphics* was used in the early 1960's and is generally attributed to the graphic designer William Fetter who worked for the Boeing Airplane Company, ibid, 101.
[129] Karen A. Frenkel, "An Interview with Ivan Sutherland," *Commun. ACM* 32, no. 6 (1989), 711. 711.
[130] George Anders, *The Rare Find Spotting Exceptional Talent before Everyone Else* (New York: Penguin 2011),. 76.
[132] Dam Andries van, "1991 Steven A. Coons Award Lecture," *SIGGRAPH Comput. Graph.* 26, no. 3 (1992), 205.
[133] Andries van Dam, "*The Shape of Things to Come*," ibid.32, no. 1 (1998), 42.

The American computer scientist Alan Kay[134] described the people who influenced the development of his works and among them was Sutherland, as he stated:

> Many of the people I admired most at this time such as Ivan Sutherland … seemed to have a splendid sense that their creations, though wonderful by relative standards, were not near to the absolute thresholds that had to be crossed. Small minds try to form a religion and the great ones just want better routes up the mountain. Where Newton said he saw further by standing on the shoulders of giants, computer scientists all too often stand on each other's toes. Myopia is still a problem when there are giants' shoulders to stand on – outsight is better than insight – but it can be minimized by using glasses whose lenses are highly sensitive to esthetics and criticism.[135]

Kay learned about Sketchpad during his years as a graduate student at the University of Utah in the fall of 1966 and described Sutherland's Sketchpad dissertation as a mandatory text that all new graduate students in the computer science department had to read, Kay related: "every newcomer got one [document]. The title was *Sketchpad: A man-machine graphical communication system*. What it could do was quite remarkable, and completely foreign to any use of a computer I had ever encountered."[136]

Sutherland was born in May 1938, in Hastings, Nebraska, but the family later moved to Scarsdale, New York.[137] His father was a civil engineer, and as a young boy the drawing and surveying instruments his father used captivated Sutherland. When he was about 12, Sutherland and his brother Bert worked for a pioneer computer scientist named Edmund Berkley.[138] It was through Berkley's electromechanical computer that performed simple mathematical additions that Sutherland first had the opportunity to work with a computer.[139] Sutherland received his B.S. from Carnegie Mellon University in 1959.[140] As a young student earning his bachelor degree in

[134] Alan kay is best known for the idea of "personal computing, the conception of the intimate laptop computer, and the inventions of the now ubiquitous overlapping-window interface and modern object-oriented programming." "Interview with Alan Kay," *Computers in Entertainment* 1, no. 1 (2003), 8.
[135] C. Kay Alan, "The Early History of Smalltalk," in *History of Programming Languages* ed. Thomas J. Bergin, Jr. and Richard G. Gibson, Jr. (ACM, 1996), 512.
[136] Ibid, 515.
[137] Henderson, *Encyclopedia of Computer Science and Technology*, 463.
[138] Edmund Berkeley was a friend of Claude Shannon, and he introduced Shannon to the Sutherland boys. Many years later, Sutherland sent a letter to Shannon and expressed his interest in the graduate program at MIT. Shannon who was a faculty at MIT invited Sutherland to visit him and became Sutherland's thesis supervisor, Frenkel, "An Interview with Ivan Sutherland." 712.
[139] Henderson, *Encyclopedia of Computer Science and Technology*, 463.
[140] Frenkel, "An Interview with Ivan Sutherland." 711.

electrical engineering at CMU, he had built various relay machines and devices using logic. Upon completing his bachelor degree he worked a summer job for IBM. He went on to earn a Masters degree in electrical engineering from the California Institute of Technology in 1959, and finally a doctoral degree in electrical engineering at Massachusetts Institute of Technology in 1963[141], where he developed his Sketchpad dissertation.

While interacting with the TX-2 computer at MIT's Lincoln laboratory, Sutherland developed a personal relationship with this computer and was given the opportunity to turn Licklider's theoretical symbiotic concept into a technological reality. The TX-2 was a large transistorized computer that occupied 1,000 square feet of space and was built by for the U.S. Air Force in 1959.[142] It had many man-machine interaction features that it had inherited from its predecessor the Whirlwind[143] computer and that Sutherland used in his Sketchpad invention. Unlike other computers in the early sixties, the TX-2 had a 7-inch, 1024 x 1024 pixel graphical display device,[144] and accepted input from a light pen and switches.[145] With the support of his thesis supervisor, the American electrical engineer Claude Shannon, known as the "father of information technology,"[146] Sutherland gained the support of Shannon's colleagues working at MIT's Lincoln laboratory and was able to make adjustments to the TX-2 computer so that it could support his Sketchpad system. Sketchpad was a revelation and in 1962, Licklider retold the story that "at the Spring Joint Computer Conference in San Francisco, during the discussion period of a session on man-computer communication chaired by Douglas Engelbart, Ivan Sutherland mentioned his Sketchpad program and, at the end of the session, showed to a few lingering enthusiasts the most dramatic on-line graphical compositions that any of them had ever seen."[147]

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141 Ivan Edward Sutherland, "Oral History Interview with Ivan Sutherland," *Charles Babbage Institute* Transcript, 45 pp.(1989). 3.

142 Kalay, *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design*, 66.

143 In 1951, MIT's Lincoln laboratory created its first Air Force-funded military computer and called it the Whirlwind. The Whirlwind is the predecessor of the TX computer, and both have the same basic design but differed in their hardware. Anne Friedberg, *The Virtual Window : From Alberti to Microsoft* (Cambridge, Mass.: MIT Press, 2006), 222.

144 Kalay, *Architecture's New Media: Principles, Theories, and Methods of Computer-Aided Design*, 66.

145 Henderson, *Encyclopedia of Computer Science and Technology*, 463.

146 Robert Lee, *Of Men and the Wind* (United States of America: Xlibris Corporation, 2010), 60.

147 Waldrop 255 – ref 42

To modern eyes Sketchpad resembles the familiar computer-aided design system, “but that’s only because Sutherland himself single-handedly pioneered most of the techniques that are now used in such programs.”[148] In the Sketchpad system, the operator would touch two points on the TX-2 display screen with the hand held light pen, and the computer would draw a straight line between them. Furthermore, the operator could draw a rough curve with the light pen and the computer would adjust the curve and smooth it out. Also, if the operator indicated that two components were attached at a specific point, then the computer would ensure that they stayed that way regardless of how the drawing was moved or rotated.[149] “Licklider was enthralled. It was as if his whole vision of symbiosis were coming to life before his eyes: dynamic modeling as it was meant to be. From then on he would point to Sketchpad as the program that had done more than any other single thing to convince the world that interactive computing was worthwhile.”[150] Licklider stated:

> In my judgment, the most important problem in computer graphics is that of establishing excellent interaction -- excellent two-way man-computer communication—in a language that recognizes, not only points, lines, triangles, squares, circles, rings, plexes, and three-way associations, but also such ideas as force, flow, field, cause, effect, hierarchy, probability, transformation, and randomness. Nowhere, to the best of my knowledge, is such interaction approached in a broad problem area at the present time… It is very frustrating to me that five and a half years have elapsed since Sketchpad passes its milepost without bringing more progress in man-computer interaction at the level of ideas and concepts.[151]

Sutherland laid out the foundation for the expansion of his Sketchpad system by allowing the system to integrate other programs in addition to the two-dimensional program he wrote. The first version handled two-dimensional drawing only, and was later extended to draw, transform, and project three-dimensional drawings of objects.[152] The flexibility of Sutherland’s invention accommodated the invention of the first graphical three-dimensional CAD program, called Sketchpad III that was also developed at MIT in 1963.

[148] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*, 256.
[149] Ibid, 256.
[150] Ibid, 256.
[151] Licklider, "*A Picture Is Worth a Thousand Words: And It Costs*." 619.
[152] David Salomon, *The Computer Graphics Manual* (London: Springer, 2011), 10.

Sutherland invented the two-dimensional Sketchpad program, while his colleague at MIT Lawrence Gilman Roberts wrote the computer program for the TX-2 computer that led to the development of the three-dimensional extension of Sketchpad, and their colleague Timothy Edward Johnson used Sutherland's two-dimensional program and Roberts' three-dimensional program to create Sketchpad's descriptive geometry drawing layout, intended to be used by draftsmen.

Like Licklider, Sutherland looked toward the act of drawing less as an end in itself and more as a means of communication with machines; thus Sutherland introduced Sketchpad as a system to make it possible for the human user to converse rapidly with the computer through the medium of line drawing.[153] "The backbone of the man-machine communication link in Computer-Aided Design is a console whose principal components are the display scope and the light pen."[154] The display scope was an ordinary cathode ray tube that the computer controlled by means of program instructions, and the light pen was a photosensitive device that responded to the light generated by an intensified point on the scope face, then transmitted this response back to the computer where it could be tested by the program.[155]

Licklider believed that the ease of interaction between the human user and the computer in the Sketchpad system was comparable to the ease of exchanging ideas and conversing among human beings, and his paper entitled *Man-Computer Symbiosis* was referenced in the Sketchpad dissertation.[156] The ideas that Licklider proposed had a direct influence on Sutherland. In that paper, Licklider described drawing as an intelligent language that humans can use to have a productive dialogue with a computer. This intelligent conversation would be conducted via input and output equipment that would use line drawings as the common language for both entities to enable them to communicate with each other on the same display screen. It was through the Sketchpad window that such a fluent dialogue via graphics between human and the computer took place.

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[153] Hookway, *Interface*, 151.
[154] Stotz Robert, "Man-Machine Console Facilities for Computer-Aided Design," in *Proceedings of the May 21-23, 1963*, *spring joint computer conference* (Detroit, Michigan: ACM, 1963), 323.
[155] Ibid, 323.
[156] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*."

Chapter Three: Sketchpad, the New Partner in Design

With the birth of the Sketchpad system, the computer suddenly became a new partner in drawing, design and decision-making. Sketchpad introduced a new drawing system originating from preexisting drawing techniques but differing in its construction and purpose. In traditional drawing, the perceiver is able to "read and interpret not only what is put on the drawing, but how it appears there."[157] It is through the process of making the drawing that the meaning of the drawing is revealed to the drafter. For example, the architect and architectural theorist Marco Frascari believed that in an architectural drawing the form does not exist before it is drawn, but rather it is present in its drawn implementation. It is this mysterious essence of drawing that makes it appropriate for architectural conception, and architects are guided by the act of drawing itself in the production of architectural drawings.[158]

This belief in the representational quality of traditional drawing departs from "the Platonic view that sees visual reality as a function of ideal essences."[159] Whereas in Sketchpad, the "drawing is assumed to be an internal mental construct of an external reality."[160] This assumption that a complete image of the drawing already exists in the drafter's mind is inherent in the nature of computer drawing.[161] These programs are constructed to aid the drafter externalize the vague image of a drawing in one's head. It is believed that computer-aided design facilitated an opportunity for human-machine collaboration via this system of visualization.[162]

According to the philosopher Hubert Dreyfus, the principles by which scientists and engineers developed computer programming in the early sixties at Massachusetts Institute of Technology, where Sketchpad was developed, really adopted the Cartesian system in their

[157] John Thomas Rule and Steven A. Coons, *Graphics* (New York: McGraw-Hill, 1961), 8.
[158] Marco Frascari, *Eleven Exercises in the Art of Architectural Drawing: Slow Food for the Architect's Imagination* (London; New York: Routledge, 2011), 16.
[159] Ibid, 9.
[160] Ibid, 9.
[161] Shi-Kuo Chang, *Visual Languages* (New York: Springer 2012), 305.
[162] Ibid, 306.

approach.[163] During his years teaching philosophy at MIT in the early sixties, Dreyfus was exposed to the developments of MIT's computer scientists working in the department of artificial intelligence, and among the pioneers in this field was Marvin Minsky who was a member of Sutherland's PhD committee and head of the artificial intelligence department at MIT in the 1960's.[164] A question that has been discussed by many scholars is: "How would you tell if a computer had produced something intelligent?" To this question, Minsky posited that a machine is being intelligent if the task it is performing would require intelligence if performed by humans.[165] Dreyfus concluded from his visit to the Artificial Intelligence laboratory at MIT in 1963 that:

> I found to my surprise that, far from replacing philosophy, the pioneers in CS [Computer Science] had learned a lot, directly and indirectly, from the philosophers. They had taken over Hobbes' claim that reasoning was calculating, Descartes' mental representations, Leibniz's idea of a universal characteristic – a set of primitives in which all knowledge could be expressed, – Kant's claim that concepts were rules … In short, without realizing it, AI researchers were hard at work turning rationalist philosophy into a research program. At the same time, I began to suspect that the critical insights formulated in existentialist armchairs, especially Heidegger's and Merleau-Ponty's, were bad news for those working in [the field of computer science and] AI researchers had condemned their enterprise to reenact a failure.[166]

Through exposure to the department of computer science and artificial intelligence at MIT and the knowledge gained from Minsky, Sutherland was aware of Cartesian concepts of representation prevalent within approaches to computer programming in the 1960's, and this Cartesian approach was the basis for Sketchpad. According to Terry Winograd, a professor of computer science at Stanford University:

> For those who have followed the history of artificial intelligence, it is ironic that [the MIT] laboratory should become a cradle of Heideggerian AI. It was at MIT that Dreyfus first formulated his critique, and, for twenty years, the intellectual atmosphere in the AI Lab was overtly hostile to recognizing the implications of what he said. Nevertheless,

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[163] Hubert L. Dreyfus, "Why Heideggerian Ai Failed and How Fixing It Would Require Making It More Heideggerian," *Artificial Intelligence* 171, no. 18 (2007), 1137.
[164] Julie A. Jacko, *Human Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications, Third Edition* (Boca Raton: CRC Press, 2012), Introduction, xxxvii.
[165] Michie, *The Creative Computer: Machine Intelligence and Human Knowledge*, 17.
[166] Dreyfus, "Why Heideggerian AI Failed and How Fixing It Would Require Making It More Heideggerian."1137.

> some of the work now being done at that laboratory seems to have been affected by Heidegger and Dreyfus.[167]

In *What Computers Can't Do*, published in 1972, Dreyfus cited Polanyi, Merleau-Ponty, and Heidegger in his early critique of artificial intelligence.[168] Dreyfus predicted that computers could be programmed to perform intelligent activities so long as they could be translated into algorithms. Such intelligent activities that can be programmable are repetitive in nature and are complex formal activities that are learned by rule and practice. On the other hand, non-formal activities that are learned by intuition and *tacit knowing* are non-programmable.

Tacit knowing relates to how tools become ways of seeing and knowing, and how certain techniques once learned may be performed without requiring conscious attention during their performance. The philosopher Michael Polanyi described the ability to possess and use knowledge without conscious awareness of its use as *tacit knowing*.[169] It has been argued that most human knowledge is tacit; including forms of knowledge that are embodied.[170]

The philosopher Martin Heidegger explored the concept of *tacit knowing* in his treatise *Being and Time* that was published in 1927, and called it *readiness-to-hand*.[171] Heidegger examined the nature of the machine and its relationship to the human body, and gave an example of the hammer as equipment possessing a being in itself. Heidegger believed that to truly understand the essence of a thing we must go beyond merely looking at it to using and manipulating it, so that we may discover what is beyond its outward appearance. Heidegger explained that this process of discovering the 'thingness' of a tool, by using and manipulating it, requires a unique sort of phenomenological insight. This phenomenological insight or *Dasein* of our being in the world allows humans to recognize the *readiness-to-hand* of a tool. Therefore, while a person is engaged in the act of drawing, *Dasein* has no conscious experience of the

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[167] *What Computers Still Can't Do: A Critique of Artificial Reason* (Cambridge, MA: MIT Press, 1992), Introduction xxxi. Quoted from Terry Winograd, "Heidegger and the Design of Computer Systems," speech delivered at the Applied Heidegger Conference, Berkeley California, December 1989.
[168] *What Computer's Can't Do: A Critique of Artificial Reason* (New York: Harper and Row, 1972), 36.
[169] Michael Polanyi, *The Tacit Dimension* (Chicago: University of Chicago Press, 2009), 11.
[170] Hookway, *Interface*, 124.
[171] Martin Heidegger, *Being and Time* (New York: Harper, 1962), 169.

machine in use as an independent object.[172] The machine as a tool-in-use is transparent. Moreover, not only is the machine part of the participating person's phenomenal world, but the user becomes absorbed in his activity in such a way that he has no awareness of himself as a subject over and against the machine. The knowledge of things as they are in the world is hidden within a knowing that is revealed through use, a knowing that is called *tacit*.[173]

For Dreyfus, early artificial intelligence research failed to appreciate the qualitative nature of tacit knowing, and any success in programming the computer to perform formal activities led to an assumption that all aspects of human intelligence would eventually become machine programmable.[174] The danger in this assumption is that: "If the computer paradigm becomes so strong that people begin to think of themselves as digital devices … [then, if] machines cannot be like human beings, human beings may become progressively like machines."[175]

In his preface to *What Computers Can't Do*, computer scientist Anthony G. Oettinger describes how "Dreyfus's own philosophical arguments lead him to see digital computers as limited not so much by being mindless, as by having no body."[176] Licklider, like Dreyfus also supported the idea of man-machine cooperation but was aware of its limitations.[177] The vision was that the Sketchpad interface would draw together the capabilities of both human and machine. Consequently, as the human user worked through the interface, the computer began to disappear and the experience of the interface took on an illusory quality. The immediate encounter of the Sketchpad interface as a thing that must be attended to blurs and fades into the experience of the interface as a form of creation. During its use, the Sketchpad interface disappears, just like a mirror seems to disappear in becoming the image of what it reflects.

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[172] Ibid, 98.
[173] Ibid, 169.
[174] Hookway, *Interface*, 130.
[175] Dreyfus, *What Computer's Can't Do: A Critique of Artificial Reason*, 192.
[176] Ibid, Introduction xi.
[177] Hookway, *Interface*, 135.

The philosopher Maurice Merleau-Ponty believed that objects are first perceived and then perceived through, and that with the inhabiting of one object; a person may grasp other objects.[178] Merleau-Ponty stated that:

> To look at an object is to inhabit it, and from this habitation to grasp all things in terms of the aspect which they present to it. But insofar as I see those things too, they remain abodes open to my gaze, and, being potentially lodged in them, I already perceive from various angles the central object of my present vision. Thus every object is the mirror of all others.[179]

Another pioneer in the field of computer graphical methods, who also believed that Sketchpad represented a step towards opening people's mind to viewing the computer as a human assistant that has some degree of intelligence,[180] was the mechanical engineering professor at MIT, Steven A. Coons. Coons helped to found the computer-aided design group at MIT in the early 1960's.[181] His students included Ivan Sutherland, Lawrence Roberts and Timothy Johnson.[182] Sutherland gained knowledge about drawing for mechanical engineering purposes from Coons who served on Sutherland's thesis committee.[183] Coons described the circumstances that initiated the concept of using computers in design, and as he related:

> In the early 1950's at M.I.T. the Servomechanism Laboratory (now the Electronic Systems Laboratory) devised and developed the first automatically controlled milling machine. The controlling information for the machine was introduced in the form of punched paper tape, on which all dimensional information and instructions for the various feed and cutter speeds were contained. At first the punched paper tape was prepared manually by some human operator who translated, in effect, the detail drawing of the part to be machined into numerical form and then into appropriate patterns of holes in the tape. This was a tedious and entirely mechanical chore, and it was only natural that short cuts in the process began to suggest themselves. The scope of such short cuts began to spread through the fabric of the technique, and it was not long before the computer was involved in implementing them.[184]

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178 Ibid, 128.
179 Maurice Merleau-Ponty, *Phenomenology of Perception* (Routledge: Psychology Press, 2002), 79.
180 Russell Morash, "Computer Sketchpad," in *Science Reporter*, ed. The Lowell Institute Cooperative Broadcasting Council (Massachusetts Institute of Technology1960s).
181 Steven A. Coons, "Applications of Computers to Automated Design" (paper presented at the Engineering Summer Conferences, University of Michigan 1965), 299.
182 Peddie, *The History of Visual Magic in Computers How Beautiful Images Are Made in Cad, 3d, Vr and Ar*. 44
183 Sutherland, "Sketchpad: A Man-Machine Graphical Communication System." 11.
184 Steven A. Coons, "An Outline of the Requirements for a Computer-Aided Design System," in *Proceedings of the May 21-23, 1963, spring joint computer conference* (Detroit, Michigan: ACM, 1963), 299.

Coons explained that, prior to Sketchpad, early computers were essentially elaborate calculating machines, and that the future of the computer through the development of the interface would expand people's minds to viewing the computer as an almost human assistant with some degree of intelligence.

Licklider compared the new bond between the human and computer with other symbiotic partnerships that exist in nature, particularly the relationship that exists between the fig tree and the insect Blastophaga grossorum. In this symbiotic relationship, both tree and insect depend on each other for their survival. In his paper titled *Man-Computer Symbiosis* published in 1960, Licklider stated:

> The fig tree is pollinated only be the insect Blastophaga grossorum. The larva of the insect lives in the ovary of the fig tree, and there it gets its food. The tree and the insect are thus heavily interdependent: the tree cannot reproduce without the insect; the insect cannot eat without the tree; together, they constitute not only a viable but productive and thriving partnership. This cooperative living together in intimate association, or even close union, of two dissimilar organisms is called symbiosis.[185]

Licklider's analogy suggests an extreme condition where the human user and computer cannot function without each other. And, although Licklider's claim is arguable, it is interesting to notice that his example implies that the computer has a presence beyond a mere tool.[186]

Coons also expressed a belief in the need for a symbiotic partnership between the human operator and computer in the following statement: "The different powers of man and machine are complementary powers, cross-fertilizing powers, mutually reinforcing powers. It is becoming increasingly clear that the combined intellectual potential of man and machine is greater than the sum of its parts."[187]

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[185] J.C.R. Licklider article "*Man-Computer Symbiosis*." Included in Institute of Radio Engineers, "Ire Transactions on Human Factors in Electronics." 4.
[186] Paul Emmons and Dalal Kassem, "Architect-Computer Symbiosis," *Montreal Architectural Review* Vol 1(2014), 51.
[187] Coons, "An Outline of the Requirements for a Computer-Aided Design System." 299.

Following Licklider's concept, Sutherland also believed that the human user and the computer could become symbiotic if allowed.[188] In the Sketchpad dissertation, Sutherland stated:

> The Sketchpad system makes it possible for a man and a computer to converse rapidly through the medium of line drawings. Heretofore, most interaction between men and computers has been slowed down by the need to reduce all communication to written statements that can be typed; in the past, we have been writing letters to rather than conferring with our computers … The Sketchpad system, by eliminating typed statements except for legends in favor of line drawings, opens up a new area of man-machine communication.[189]

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[188] Ibid.
[189] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 8.

Chapter Four: Sketchpad and Architecture

Perhaps the first introduction of the Sketchpad invention to architects was made through a conference titled *Architecture and the Computer* that was held at the Boston Architectural Center[190] in Massachusetts in 1964.[191] Coons presented his paper titled *Computer Aided Design*[192] at this conference and described in detail the Sketchpad system and the potential symbiotic partnership that architects can have with computers.[193] Among the architects who presented at the conference were Walter Gropius[194] and Christopher Alexander.[195] The *foreword* to the conference proceedings, written by architecture professor Sanford R. Greenfield, noted that:

> At no time was it our purpose to accelerate computer use or to try to apply the computer to architectural design. The most obvious examples of current use of the computer are to be found on the periphery of the architectural profession, among structural and mechanical engineers, city planners, contractors, etc.… I would guess that the reports on computer graphics were most significantly related to architectural design. Professor Coons of M.I.T. demonstrated with SKETCHPAD that it is possible to communicate with the machine by drawing. A language in which architects have been trained … It is, perhaps, ironic that SKETCHPAD and computer graphics, the two tools most readily adaptable to the architect's work, themselves pose the greatest threat to his traditional role. The conference failed to discuss this aspect … In retrospect, the conference seems to have served at least to alert the profession to an irresistible force which will readily

[190] The Boston Architectural Center was an evening school of architecture for people apprenticed in architects' offices throughout Boston who were unable financially to afford tuition at either Harvard's Graduate School of Design or MIT's School of Architecture. Professionals willing to donate their time staffed the center's school and most of the students worked in local architectural offices during the day, and received their education at the Boston Architectural Center during the evenings. The Center was authorized by the Massachusetts Department of Education to construct classes on a certificate-granting basis, and both Harvard and MIT gave full credit for its courses. Boston Architectural Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts* (Boston Architectural Center, 1964), Preface V.

[191] Ibid, Preface V.

[192] Coons published another paper that was also titled *Computer Aided Design* but was published in 1966.

[193] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 26.

[194] Walter Gropius was a German architect and founder of the Bauhaus School. Sigfried Giedion, *Space, Time and Architecture : The Growth of a New Tradition* (Cambridge, MA.: Harvard University Press, 1982), 487.

[195] All three speakers: Steven Coons, Walter Gropius and Christopher Alexander presented their papers on the same day of the conference. Furthermore, Marvin Minsky, who is one of Sutherland's committee members, participated in a panel discussion on the same day as well. Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, vii.

> alter the practice of architecture whether we plan for it or not. It is a force that can be controlled and directed to fulfill those values we judge essential, but only if we understand it and its relation to our traditional role. Material published since December 5, 1964, suggests that the First Boston Architectural Center Conference did, in fact, serve its purpose: the profession appears concerned with the problems that have been raised. The issue is no longer dormant.[196]

Perhaps the earliest evidence of the intention to integrate computers in the architectural drawing process can be traced back to a conference proceeding paper that was referenced in the Sketchpad dissertation. The paper was titled *On-Line Man-Computer Communication* by J. C. R. Licklider and Welden E. Clark, and was published in 1962. During the publication of this paper, the man-computer symbiosis idea was at an early stage of development and the potential of it as a useful system had not yet been completely formalized. Among the preliminary directions in which advances were being investigated was the field of planning and design. It was hoped that eventually the computer would be developed to aid in the planning and design phases of architectural and constructional problems. The authors started their exploration of computer-aided planning and design with the design of hypothetical hospitals. It was believed that hospitals posed an interesting and difficult challenge in design because of the many technical constraints associated with medical equipment, circulation, communication, and transportation.[197] The computer was used to aid in the design of the floor plan by producing graphics that displayed anticipated time distribution of patient circulation in the hypothetical hospitals, and by making a partial floor plan sketch of one floor in the hypothetical hospital; however, these drawings were created using punch cards, and the computer lines produced in the plan were dots instead of a continuous line as would later be drawn in the Sketchpad system.[198]

While Gropius encouraged the exploration of the potentialities of using computers for architectural design, he emphasized the dangers of mechanization when it is allowed to take over production. In order to communicate his position on mechanization, Gropius, in his paper titled *Computers for Architectural Design,* quoted the architecture historian Siegfried Giedion:

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[196] Ibid, xi.
[197] J. C. R. Licklider and Welden E. Clark, "On-Line Man-Computer Communication," in *Proceedings of the May 1-3, 1962, spring joint computer conference* (San Francisco, California: ACM, 1962), 117.
[198] Ibid, 126.

> In his remarkable book, *Mechanization Takes Command*, Siegfried Giedion says: Mechanization is an agent, like water, fire, light. It is blind and without direction of its own. It must be canalized. Like the powers of nature, mechanization depends on man's capacity to make use of it to protect himself against its inherent perils. Because mechanization sprang entirely from the mind of man, it is the more dangerous to him. Being less easily controlled than natural forces, mechanization reacts on the senses and on the mind of its creator.[199]

Gropius then stated that: "To control mechanization demands an unprecedented superiority over the instrument of production. It requires that everything be subordinated to human needs."[200] Gropius did not make clear his position on treating the computer as merely an instrument for production or a partner in design, but emphasized that architects should not be quick to dismiss the use of computers all together. He stated:

> We seem to be always wrong when we close the door too early to suggested new potentialities, being often misled by our natural inertia and aversion to the necessity of transforming our thoughts. Being not at home in the vast new field of computer systems, I want to be cautious. Still, I believe if we look at those machines as potential tools to shorten our working processes, they might help us to free our creative power.[201]

Christopher Alexander, however, did not hesitate in rejecting the computer completely as a useful tool and partner in the process of design. Alexander criticized the symbiotic relationship that architects were beginning to have with a computer when collaborating on an architectural design. In his paper entitled A *Much Asked Question about Computers and Design* Alexander stated that:

> A digital computer is, essentially, the same as a huge army of clerks,[202] equipped with rule books, pencil and paper, all stupid and entirely without initiative, but able to follow exactly millions of precisely defined operations. There is nothing a computer can do which such as army of clerks could not do, if given time… In asking how the computer

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[199] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 41. Gropius cited Giedion from Sigfried Giedion, *Mechanization Takes Command, a Contribution to Anonymous History* (New York: Oxford Univ. Press, 1948), 714.
[200] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 41.
[201] Ibid, 41.
[202] A clerk is "a person employed in an office or bank to keep records, accounts, and undertake other routine administrative duties." Angus Stevenson and Maurice Waite, *Concise Oxford English Dictionary* (Oxford; New York: Oxford University Press, 2011), 325.

> might be applied to architectural design, we must, therefore, ask ourselves what problems we know of in design that could be solved by such an army of clerks … At the moment, there are very few such problems[203]

Using a computer to design hospitals was the source of Alexander's criticism when Sketchpad was introduced to architects for the first time.[204] Alexander believed that Licklider and Clark's approach to designing that hospital concentrated on an insignificant aspect of hospital design, by creating a floor layout with the shortest possible distance between the physicians' offices and patients rooms, and ignoring more important aspects of architectural design, such as making spaces that improved the well-being of patients and promoted earlier recovery.[205] Alexander stated:

> Experimental psychology,[206] obsessed by the idea of rigorous mathematization and hypothesis testing, has for the last forty years, by-passed the significant problems of human behavior, and dealt only with those trivial aspects that happen to be the easiest to make precise… It will happen whenever someone sets out to apply the computer to design. We may see it, for example, in a recent study of computer aided planning in hospital design. [Alexander then describes in detail how the computer was applied in that hospital design, based on the amount of traffic between rooms of different types] … Any designer may rightly feel perplexed by this complexity. But if he strips the hospital design problem down to those aspects that can be measured or encoded, he will eliminate just that complexity which made the problem seem difficult to begin with. It is ironic that the very tool invented to unravel complexities imposes such severe restrictions on the design problems it can solve, and that the real source of complexity has to be eliminated before the tool can ever get to it[207]

In an earlier publication entitled *Notes on the Synthesis of Form* published in January 1964,[208] Alexander observed:

[203]Center, Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts, 52.
[204] "Architecture and the Computer; Proceedings, First Boston Architectural Center Conference" (Massachusetts, Boston, 1964), Preface V.
[205] Ibid, 53.
[206] As mentioned previously, Licklider was an experimental psychologist and computer scientist.
[207] Center "Architecture and the Computer; Proceedings, First Boston Architectural Center Conference." 54.
[208] Christopher Alexander's "Notes on the Synthesis of Form" was inspired by MIT work in the 1960's. Emily Abruzzo, Eric Ellingsen, and Jonathan D. Solomon. *Models* (New York, 306090, Inc Publishers Group, UK, 2007), 55.

> Today, functional problems are becoming less simple. But designers rarely confess their ability to solve them. Instead, when a designer does not understand a problem clearly enough to find the order called for, he falls back on some arbitrarily chosen formal order. The problem, because of its complexity, remains unsolved.[209]

In his book entitled *Computer Aided Architectural Design* published in 1977,[210] architect William J. Mitchell explained that Sutherland's Sketchpad system led the way for the development of computer-aided design programs that were adopted in architecture and that it was an appropriate drawing tool for the architect because it allowed the drafter to make freehand sketches on the computer tablet. As he stated:

> Beginning with I. E. Sutherland's very important pioneering Sketchpad system, an enormous amount of effort has been devoted to development of graphic input techniques which enable a user to sketch on the refreshed CRT using a light-pen… The most natural and general mode of graphic communication for an architect is the rapid and unconstrained freehand sketch.[211]

Sketchpad and Architects Today

In a more recent reflection on the relationship between architects and computers in computer aided architectural design systems, architecture professor Ingeborg Rocker expressed her suspicion of the degree of involvement that computers have in conceptualizing architecture designs. She chronicled discussions between the human user and the computer informing current architectural processes, stating that:

> Nietzsche had argued, sitting half-blind in front of his typewriter, that his new writing tool was 'working on his thoughts.' Today, sitting in front of a computer, one may have similar suspicions - how is this new tool working on one's thoughts, and thus on one's

[209] Christopher Alexander, *Notes on the Synthesis of Form* (Cambridge; London: Harvard University Press; Distributed by Oxford University Press, 1964), 1.
[210] William J. Mitchell, an architect and urban theorist, was a former dean of the School of Architecture (1992-2003) at MIT and head of the media arts and sciences at the school's Media Lab. He predicted the application of computers to architectural design. One of his pioneering works in this area is his book *Computer-Aided Architectural Design* that was published in 1977. William Grimes, "William J. Mitchell, Architect and Urban Visionary, Dies at 65," *The New York Times* 2010, 19.
[211] Mitchell, *Computer-Aided Architectural Design*, 325-329.

> architecture"? She concluded that computation and computer technologies of representation have affected modes of conceptualizing architecture as much as they have impacted the modes of production.[212]

Architect and founder of MIT's media lab Nicholas Negroponte described in his book entitled *The Architecture Machine: Toward a More Human Environment,* published in 1970, that a removal of the barriers between architecture and computing by creating an intimate association between two dissimilar species, the designer and machine. This would be achieved through mutual training and a collaborative effort where both the designer and the machine tracked the other's design maneuvers.[213] However, Negroponte believed that architects use hand gestures to communicate their thoughts, and that these important hand movements would be lost in any partnership with the computer.[214] (See Figure 4)

[212] Ingeborg Rocker, "Interface: Between Analog and Digital Systems," in *LIFE information, On Responsive Information and Variations in Architecture: Proceedings of the 30th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA)* (New York, New York: Cooper Union, Pratt Institute, 2010), 53.
[213] Nichoas Negroponte, *The Architecture Machine: Toward a More Human Environment* (Cambridge: MIT Press, 1970), 11.
[214] Andrea Gleiniger and Gruyter de Vrachliotis, *Code: Between Operation and Narration*, trans. Laura Bruce (Switzerland: Birkhäuser, 2012), 78.

Figure 4: The architect's hand gesture lost on the computer. (Drawn by the author)

The philosopher Ivan Illich examined the influence of the computer on the human user in his essay *Silence is a Commons,*[215] published in 1983.[216] Interestingly, the essay was subtitled "Computers are doing to communication what fences did to pastures and cars did to streets." Illich believed that computers posed a danger to human beings and warned against depending on these machines for communication. He argued that human beings tended to give up their responsibilities to machines, and believed that eventually human beings would become subservient to the system. In the "Computer-Managed Society" Illich stated that:

> Such machines force people to behave like machines. The new electronic devices do indeed have the power to force people to communicate with them and with each other on

[215] Ivan Illich (1926-2002) was an Austrian philosopher, Roman Catholic priest, and social critic who was interested in the practice of education. Steve Chalke, *Being Human* (UK: Hodder & Stoughton, 2015), 46.
[216] Ivan Illich, "Silence Is a Commons: Computers Are Doing to Communication What Fences Did to Pastures and Cars Did to Streets," *CoEvolution Quarterly* (1983), 4.

> the terms of the machine. Whatever structurally does not fit the logic of machines is effectively filtered from a culture dominated by their use.[217]

Furthermore, Illich believed that speech, which an inextricably intimate part of a human being, is vulnerable, and can "easily be destroyed by the encroachment of modern means of communication."[218] Furthermore, "we could easily be made increasingly dependent on machines for speaking and for thinking, as we are already dependent on machines for moving."[219] Illich believed that such a change to our modes of communication would be the "most fundamental form of environmental degradation."[220]

Regardless of architects' willingness to accept computers as partners in decision making, it was easy to impose this new partner on architects that used computers as drawing tools, because the architect often failed to recognize the presence of this partner whilst actually using the computer, and did not realize that this new partner was, from the moment of engagement in that process, always part of design decision making.

According to Negroponte in his book *Being Digital*,[221] "Sketchpad exploded upon the world the idea of interactive computer graphics," and Sutherland's achievement was of: "such magnitude that it took a decade to truly understand and appreciate all of his system's contributions.[222] Coons stated that: "The Sketchpad system thus introduced the basic tools for computer-aided design,"[223] and offered, in Negroponte's opinion, a comfortable and easy way in which humans could express their ideas graphically. As Negroponte stated: "Good human-computer interface design included the computer understanding incomplete, ambiguous thoughts, typical of the early stages in any design process, versus the more complete and consistent presentations of complex, finished renderings."[224]

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[217] Ibid, 4.
[218] Ibid, 4.
[219] Ibid, 4.
[220] Ibid, 4.
[221] Nicholas Negroponte is a founder and the director of the Massachusetts Institute of Technology's Media Laboratory. He founded MIT's Architecture Machine Group, a combination lab and think tank. Rosemary et al., "*50 Years after: We May Think*." The Brown/MIT Vannevar Bush Symposium." 53.
[222] Negroponte, *Being Digital*, 103.
[223] Steven A. Coons, "Computer-Aided Design," *Design Quarterly*, no. 66/67 (1966), 12.
[224] Negroponte, *Being Digital*, 104.

In her paper *Interface: Between Analog and Digital Systems,* published in 2010, Rocker described the impact that the Sketchpad system had upon architectural practices. Rocker believed that the user of the Sketchpad system was limited in the shapes that users could draw on the Sketchpad window, and therefore the future of interactive computer graphics was determined by the limitations of Sketchpad. For example, Rocker asserted that because curves were a major challenge to the Sketchpad program and were limited to shapes based on arcs of circles, this technical limitation ultimately restricted designs to geometries that could be represented through Sketchpad window technology.[225] Curiously, Alberti limited the architect's geometry to straight lines and arcs as well. In his treatise *De Re Aedificatoria*, translated as *On the Art of Building in Ten Books*, written in the mid-15th century, Alberti stated that:

> A line may be either straight or curved: there is no need here to deal with lines that spiral like a snail shell or a whirlpool. The straight line is the shortest possible line that may be drawn between two points. The curved line is part of a circle. A circle is the line made by one of two points moving on one plane … the curved line, which we called a part of a circle, will be known as an arc.[226]

Rocker believed that the choice of medium informed how design is represented and what that design suggested. As a result, whilst: "Sketchpad's constraints were, to a large extent, ensuring the success of the program and planting the seeds for interactive computer graphics programs to come, it also set an agenda for how the computer was used as a drawing aide and how certain geometries could be more favored than others."[227]

In addition, since repetition of already established geometries required less effort than inventing new ones, the computer reinforced the repetition of the same as more effective than developing the new.[228]

Another factor that may have influenced the development of computer applications for architectural uses was the faulty assumption that architects and engineers depended on their drawing tools to solve design problems in the same way. According to Coons: "General

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225 Rocker, "Interface: Between Analog and Digital Systems." 57.
226 Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach, and Robert Tavernor (Cambridge, MA: MIT Press, 1988), 19.
227 Rocker, "*Interface: Between Analog and Digital Systems*." 57.
228 Ibid, 57.

problems of the architect, the machine designer, and the electronic designer are the same, but the specific details of their problems bear scant resemblances one to another. Yet an appropriately designed system will be so flexible that it will enable each discipline to modify the structure to fit its purpose."[229]

Sketchpad and Engineering

Engineers increasingly became interested in using machines and computers for manufacturing purposes. For instance, prior to Sketchpad, there was an earlier computer-aided manufacturing and drafting system invented in 1956 by a group of engineers at the Boeing Company for the purpose of constructing airplane parts.[230] However, unlike Sketchpad that had a computer monitor and allowed the user to draw directly on the monitor with a light pen, the Boeing Company's system did not have a computer monitor, a light pen, and no electronic drawing. Their system was a numerically controlled computer system that relied on punch cards as its source of input data.[231]

The Boeing Company had developed their computer-aided manufacturing system during the late 1950's prior to their computer-aided drafting system because it was easier to program the computer to perform the mechanical task of cutting metal than it was to create a computerized system for drafting. Their computer-aided manufacturing system was used to scribe line drawings on a two-dimensional sheet of metal. This was achieved by using the Boeing Company's computer controlled three-dimensional milling machine to scribe a two-dimensional drawing on a sheet of aluminum, thereby creating the first computer-aided drafting system in 1961.[232]

The engineer Norman Sanders, who was involved in the invention of the computer-aided manufacturing and drafting systems at the Boeing Company, recounts the story of the invention: "If you can cut in three dimensions, you can certainly scratch in two. Don't do it on paper, do it

[229] *Coons, "An Outline of the Requirements for a Computer-Aided Design System.*" 302.
[230] Norman Sanders, "An Industry Perspective on the Beginnings of Cad," *SIGCSE Bull.* 40, no. 2 (2008), 128.
[231] Ibid, 132.
[232] Ibid, 132.

on aluminum. It had the simplicity of the paper clip! … We simply replace the cutter head of the milling machine with a tiny diamond scribe (a sort of diamond pen) and drew lines on sheets of aluminum."[233]

Unlike the simplicity of drawing with the light pen in Sketchpad, the Boeing Company's system required that the user rely on punch cards as input data to create the line drawing. Furthermore, as the following chapters will reveal, the concept of connecting Sketchpad to manufacturing systems was the objective of the three-dimensional expansion of Sketchpad.

Another interesting aspect of Sketchpad for engineers was its capability to perform repetitive tasks. Licklider imagined that computers could behave like assistants rather than like calculators. In the partnership with the computer, the operator established goals and the computer took action in support of those goals. In this process, computers were active participants in getting work done, and engaged with their users in ongoing activities.[234]

Licklider referred to computer hardware as "Desk-Surface Display and Control", and compared the way in which it could help people in tedious tasks to the way in which colleagues with different sets of skills could help in similarly tedious circumstances. In Licklider's statement on the symbiotic system, the computer is described as "another engineer": "That could correct the computer's data, instruct the machine via flow diagrams, and in general interact with it very much as he would with another engineer, except that the other engineer would be a precise draftsman, a lightning calculator, a mnemonic wizard, and many other valuable partners all in one."[235]

Clearly from his statement, Licklider preferred to emphasize the benefits of this symbiotic partnership with the computer, and underlined how the computer would be able to specifically satisfy the needs of the engineer working with the computer. He suggested that:

> The operations that fill most of the time allegedly devoted to technical thinking are operations that can be performed more effectively by machines than by men… If those problems can be solved in such a way as to create a symbiotic relation between a man

[233] Ibid.
[234] P. Maglio Paul and S. Campbell Christopher, "Attentive Agents," *Commun. ACM* 46 no. 3 (2003), 47.
[235] Licklider, "*Man-Computer Symbiosis*."

> and a fast information-retrieval and data-processing machine… the cooperative interaction would greatly improve the thinking process.[236]

Licklider believed that the engineer's intellectual strength would be enhanced through this coupling with the computer. As he stated: "The hope is that, in not too many years, human brains and computing machines will be coupled together very tightly, and that the resulting partnership will think as no human brain ever thought and process data in a way not approached by the information-handling machines we know today."[237]

Licklider predicted that a partnership between the human and the computing machine would result in a more powerful human able to think and process data in a manner beyond any technology available up to 1960.

As an electrical engineer, Sutherland's area of expertise revolved around graphics that accompanied electrical engineering drawing. Through Sketchpad, Sutherland was able to translate his knowledge of engineering drawing and drafting to another form applicable to computers.[238]

In the partnership with Sketchpad, the engineer benefits from the computer's skill of following a set of rules to arrive at the optimum design solution for a predetermined design question, whereas the architect cannot benefit from the computer's skill because the architect does not begin the design with a predetermined design question. Mitchell described the nature of the tasks that could be performed by computers as rudimentary in nature, to the extent that these tasks would not require any thinking and relied on following a sequence of steps.[239]

Frascari had a different view of the role of repetitive and mundane tasks in creative thinking. He believed that computers give the illusion of relieving the drafter of monotonous tasks such as hatching, cross-hatching, scribbling, and stippling, resulting in more efficient drawing production. However, these mundane tasks are part of the drafter's creative thinking; therefore, by eliminating this part of the original experience of drawing, the drafter loses the time for the mind to productively wander and daydream. Furthermore, neuroscientists have

[236] Ibid, 6.
[237] Ibid, 4.
[238] Peddie. *The History of Visual Magic in Computers How Beautiful Images Are Mad. In Cad 3D. VR and AR*. 102.
[239] Michie, *The Creative Computer: Machine Intelligence and Human Knowledge*.

discovered that daydreaming is an essential part of the mode of thought, and that while the drafter is daydreaming through repetitive tasks he is able to subconsciously move his attention from the immediate task to sort through important problems.[240]

Consequently, by replacing the human user with the computer in completing the mundane tasks of a drawing, the drafter became increasingly disengaged from the design. While it was believed that Sketchpad would relieve the drafter from the mundane tasks and free his attention to engage in more productive thinking related to design, it is more likely that the human user would have difficulties concentrating on the automated computer system that completed many of the tasks once completed by humans. As the drafter became increasingly disengaged in the Sketchpad system, the human user's thoughts were more likely to wander and devote thinking time to thoughts unrelated to design.

Unlike the design process of an architectural project that depends on the skill, creativity and originality of the architect performing the task, engineering related tasks usually depend on efficiency in solving a problem using the most appropriate mathematical solution requiring the least amount of time. Consequently, in many situations the computer would be an appropriate tool for engineering related tasks, but an inadequate tool for most architectural related tasks.

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[240] Frascari, *Eleven Exercises in the Art of Architectural Drawing: Slow Food for the Architect's Imagination*, 154.

Chapter Five: Sketchpad's Winking Face

The Sketchpad interface went beyond presenting a new method of interacting with the computer; it implied a close relationship comparable to relationships built with other human beings. Sketchpad's interface, while it was a form of technology, was also a form of actually relating *to* technology.

According to the cultural theorist Branden Hookway in his book entitled *Interface*, the interface precedes the technology in a manner similar to a person who encounters a mirror image before the mirror itself.[241] At the very moment that the human user and computer come into contact, their encounter is subject to a process of mediation. This mediation between the human and computer is similar to a gateway through which the human experience is situated with respect to the outside world. The human activities that are transported through this gateway are limited by the capabilities and operations of the interface.

The most essential component of the Sketchpad interface lies not in the individual qualities of any entity, but rather in the qualities of relation between entities. Hookway defined the term *interface* as follows:

> The interface is a form of relation that obtains between two or more distinct entities, conditions, or states such that it only comes into being as these distinct entities enter into an active relation with one another … its overall activity brings about the production of a unified condition or system that is mutually defined through the regulated and specified interrelations of these distinct entities.[242]

The new expectation that the computer could become a life-like partner was a consequence of the use of the cathode ray tube as the computer's monitor. The effectiveness of Sketchpad's representations depended upon the immobile spectator, who witnessed manipulation of the drawing confined to the frame. Film theorists sought to account for the experience of the

[241] Hookway, *Interface*, 1.
[242] Ibid, 4.

spectators sitting immobile in front of moving images and yet experiencing changes in their point of view.[243]

The relationship between the immobile spectator and the animated scene contained within the virtual window was discussed by the German philosopher Walter Benjamin in his essay titled *The Work of Art in the Age of Mechanical Reproduction,* published in 1936.[244] Benjamin believed that in the new age of mechanical reproduction, the contemplation of a scene in a virtual window and the nature of the film had changed. Rather than the viewer absorbing the scene as an individual, the animated scene of the film drew the spectators collectively into the scene.

I would argue that there is a strong relationship between the tradition of film and the Sketchpad invention. Coons described the Sketchpad interface as both a television and a pad. He described it as "a screen very much like the screen of a television set."[245] With Sketchpad, Sutherland had the opportunity to create a partner in a TV-like monitor. Furthermore, "Sutherland recognized the importance of visuality in a world fascinated by film, television, and advertising, and he sought to locate related practices in the computer."[246]

The Sketchpad system displayed virtual drawings on an electrical window. Alan Curtis Kay, an American computer scientist and a pioneer in the field of windowing graphical user interface design, referred to Sketchpad's computer monitor as a window that allowed the drafter to draw on a "virtual canvas".[247] Kay's description of Sketchpad's window depicts an image of a painter standing in front of a woven fabric stretched across a vertical wooden frame similar to the image of a Renaissance painter standing in front of his vertical canvas on an easel. Although electrical representations like those created on the computer monitor are often referred to as virtual representations, the term virtual is not limited to electrical drawings made on the computer screen. Virtual is a term that refers to any representation of an object constructed with a medium different than the original medium of the object itself, such as drawing.

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[243] Friedberg, *The Virtual Window: From Alberti to Microsoft*, 150.
[244] Walter Benjamin and Hannah Arendt, *Illuminations* (New York: Schocken Books, 1986), 239.
[245] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 26.
[246] Jeff Rice, *The Rhetoric of Cool: Composition Studies and New Media* (IL: Southern Illinois University Press, 2007), 137.
[247]Alan Kay, ed. new media reader, "Earliest Known Footage of Ivan Sutherland's MIT PhD Dissertation Sketchpad," ed. Alan Kay(1962).

According to the film theorist Anne Friedberg in her book titled *The Virtual Window*, "the term virtual serves to distinguish between any representation or appearance whether optically, technologically, or artisan produced that appears functionally or effectively but not formally of the same materiality as what it represents."[248]

In the earliest drawing devices of the Renaissance, for example the Renaissance architect Leon Battista Alberti's perspective device and the Renaissance painter Albercht Dürer's perspective machine that was derived from it, the Cartesian coordinate system was not yet invented and the ideas associated with it did not exist. However, there was a different drawing system that was visible to the drafter and fundamental to the drawing process, and that was the grid. According to Alberti in his treatise *On Painting*, the grid that is woven into the veil of the perspective device aids the human user in organizing the components of the painting in their appropriate location within the frame of the painting, Alberti stated:

> A further advantage consists of the fact that in a panel to be painted, the positions of the edges and the limits of the surfaces can easily be established in very precise locations. In fact, when you observed over here in a parallel the forehead, in the very next the nose, in the near one the cheeks, in the lower the chin, and all things of that kind, situated in their own places, in the same way there, you will have placed in the best manner all the things on a panel or on a wall, also subdivided by corresponding parallels.[249]

Alberti's grid aids the painter in organizing elements in the space of the painting construction. This space is not a natural quality of the real world; rather, it is a space that is constructed by the painter. The grid enables the drafter and the perceiver to step back from the constructed scene at a certain distance from the vertical canvas and examine the scene as if looking at the world through a window. Alberti's carefully planned organization resulted in a space that can be inhabited by the drafter and the perceiver. This organization is based on measurements that can be determined by following a sequence of mathematical procedures.[250]

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[248] Friedberg, *The Virtual Window: From Alberti to Microsoft*, 10-11.
[249] Leon Battista Alberti, *Leon Battista Alberti: On Painting*, trans. Rocco Sinisgalli (Cambridge: Cambridge University Press, 2011), 51.
[250] Alberti's drawing technique relied on using orthographic lines to arrive at the perspectival representation of an object. For example, in Alberti's drawing of the checkerboard pavement, the drawing construction embodied the rules for combining two or more views of a scene. To achieve this, he superimposed upon the front view of the orthogonal lines of the pavement a second, side view, which produced an accurate progression of the spatial intervals marked by the pavement's horizontal lines. The determining factors in obtaining the perspectives of the lines of the pavement are the height of the viewer and his distance from the plane of projection. Alberti's drawing is scaled to the height of an average person and proportioned to a selected distance between him and the base of the

The grid played an important role in the development of twentieth-century computer graphics.[251] The gradual development of the grid from the Renaissance toward the twentieth century corresponded with an increasing interest in natural science. The use and meaning of the grid significantly changed in the seventeenth-century through the writings of the philosopher Rene Descartes, particularly his treatise titled *Discourse on Method*, published in 1637.[252] "Descartes [laid] the foundation for an analytical geometry which defines the position of coordinates and axes – conceived as numerical quantities – on a plane in space."[253]

Sketchpad's Cartesian coordinate system operated as a container for the virtual elements that the drafter created in the computer's space. It also enabled the drafter and the perceiver to measure the distance, size and location of the elements in the computer's space. As a result, the Cartesian axis of drawing transformed the computer world into a synthetic field into which the elements could be inserted and arranged. Unlike the visible Renaissance grid, Sketchpad's Cartesian system was a system of representation that is based on invisible coordinates that the drafter could not see but knew existed in the computer's drawing space.

Alberti intended for the perspective device to be used by painters, and argued against it being used by architects, pointing out the differences between the perspectival techniques of the painter and the mathematically accurate documents the architect must produce, which cannot be achieved through the use of perspective. Alberti stated that:

> Between the design (disegno) of the painter and that of the architect, there is this difference: that the painter, by the exactness of his shades, lines, and angles, endeavors to make the parts seem to rise from the canvas; whereas the architect, without any regard to the shades, makes his reliefs from the design of his plan, as one that would have his work valued, not by apparent perspective, but by the real compartments founded upon reason.[254]

Alberti believed that the strength of the painter's perspective drawing lay in its visual deception through shades, lines, and angles that help to create an illusion that deceives the observer, and makes the drawing apparently an extension of the real world.

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pyramid on which the pavement is projected. Joan Gadol, *Leon Battista Alberti: Universal Man of the Early Renaissance* (Chicago: The Univ. of Chicago Press, 1969), 45.

[251] Jack H. Williamson, "The Grid: History, Use, and Meaning," *Design Issues* 3, no. 2 (1986), 15.

[252] Ibid, 20.

[253] Ibid, 20.

[254] Alberti, *On the Art of Building in Ten Books*, 34.

Dürer later developed a more complex version of Alberti's perspective hardware that involved the pulling of strings through canvas. One of Dürer's machines was illustrated in a 1525 woodcut called *Artist Drawing a Lute*, and was mechanical in nature in that it hardly required any understanding of the art of perspective construction in the drawing process – so much so that Dürer's woodcut illustration depicted two blind men drawing a lute by relying only upon his mechanical hardware.[255]

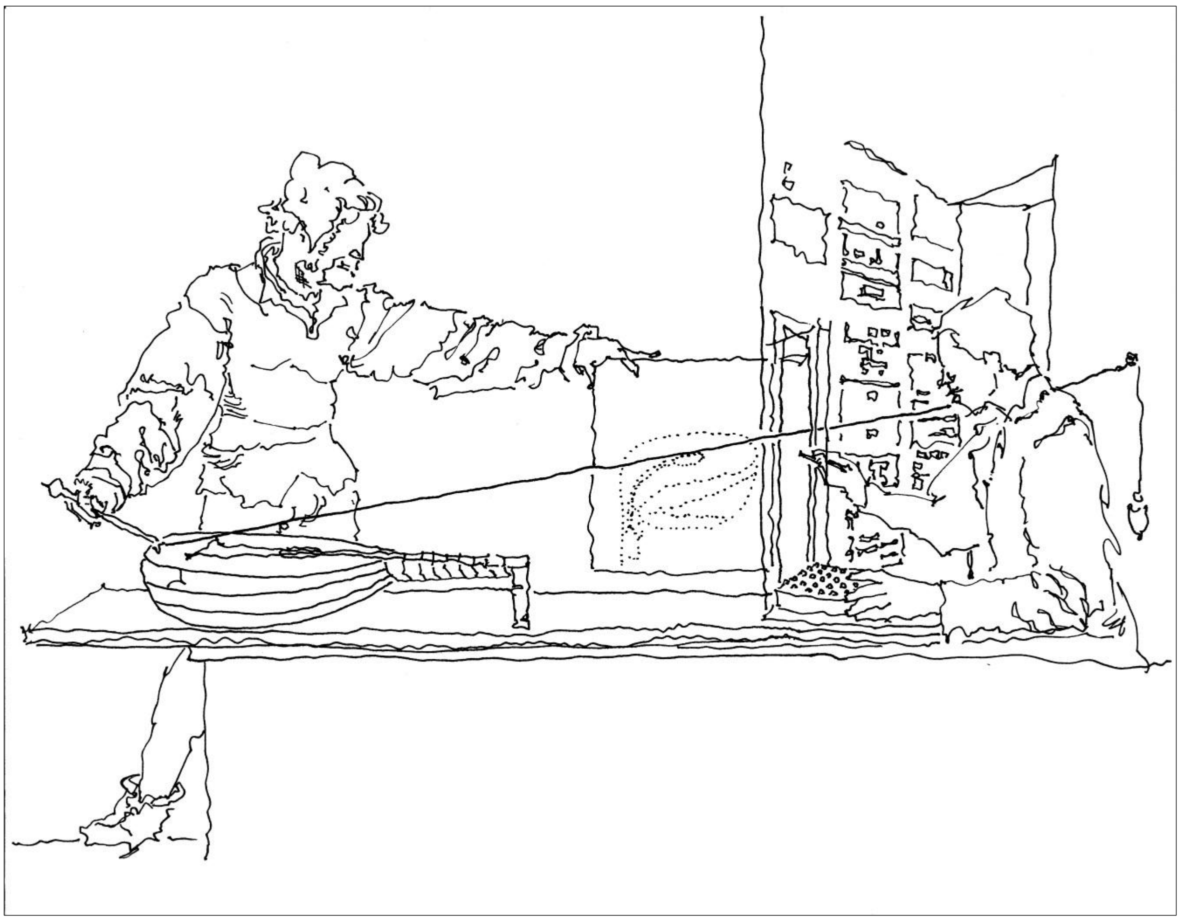

Figure 5: Drawing Albercht Dürer's lute on Sketchpad's window. (Drawn by the author)

[255] Stan Allen, *Practice: Architecture, Technique and Representation* (Routledge: Taylor & Francis, 2012), 10.

With the aid of the Sketchpad system, much like Dürer's machine, the laborious process required to create perspective representation became unnecessary. (See Figure 5) With the reliance on the computer system to complete the process of creating a perspective drawing, the human user lost an understanding of the visual principles of such composition, and the visual structure of the object in the environment. Prior to the invention of Sketchpad, the detailed process of creating perspectival representation revealed to the drafter the actual structure of the physical world. However, Sketchpad did not allow the human user to experience the same basic techniques during the drawing process as could be achieved with traditional drawing tools. Instead, the computer took on part of the drawing process and the human user gave up this essential role in the development of drawing.

The Sketchpad interface is a threshold condition that marks the boundaries of a space for a kind of inhabitation, and opens up new situations for exploration and participation. The etymology of *interface* can be understood from the prefix *inter* and the etymology of *face*. Inter pertains to an inward orientation that encompasses relations that occur within a bounded field. This meaning of inter suggests that an interface does not define its bounding field but is rather *defined by them*.[256] Thus, the interface is an interior condition whose activity is constrained within the boundaries given by its participating entities.

In the Sketchpad system, the interface is used as a form of communication between two entities. The role of the interface is the translation and transmission of that which its bounding entities project into it. The etymology of the face points toward an outward orientation and an exteriority. *Face* is derived from the Latin *facies*, meaning visage, and *facies* is derived from the verb *facere* that means to act and bring about.[257] A face looks outside itself and is oriented toward an exterior.

The combination of these two contradicting conditions: *inter* – an interior condition and *face* – an exterior condition, makes the interface the embodiment of contradiction.[258] Thus, in combination, the Sketchpad interface is one between faces and a facing between. And through Sketchpad's human-computer symbiosis, the interface is fully bounded by the faces of both the

[256] Hookway, *Interface*, 7.
[257] Ibid, 8.
[258] Ibid, 9.

human and the machine. The Sketchpad interface offered an alternative approach to using the computer and implied such a powerful relationship that it was in some instances described as or imagined to be another 'being in itself'. Sutherland identified this 'other being' in his dissertation as a “winking Nefertiti”.[259] (See Figure 6)

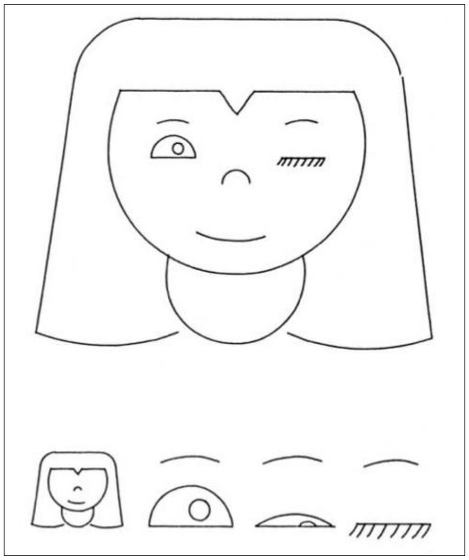

Figure 6: Winking Girl Nefertiti, Ivan Sutherland, "Sketchpad: A Man-Machine Graphical Communication System" (Massachusetts Institute of Technology, 1963), 109. (By Courtesy of MIT)

Nefertiti was an Egyptian queen who ruled Egypt during the fourteenth century. Nefertiti, whose name means: “the beautiful has come,”[260] is still considered an iconic beauty due to a bust of her that was found in 1912, and is currently being exhibited in the Berlin Neuse Museum.[261]

[259] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 132.
[260] Mary Englar, *Nefertiti of Egypt* (Mankato: Capstone, 2009), 14.
[261] Andrea Schulte-Peevers, Anthony Haywood, and Sally O'Brien, "Berlin," Lonely Planet, 90.

Figure 7: Face-to-face interaction with winking Nefertiti through Sketchpad's televisual cathode-ray tube. (Drawn by the author)

Nefertiti existed on the "other side" of the Sketchpad window and shared a private relationship with Sutherland, expressed in the gesture of a wink. In his dissertation, Sutherland developed a series of changing left eye components to make Nefertiti actually appear to wink from Sketchpad's window at the operator. Sutherland's reference to Egypt's beautiful queen could be interpreted as an expression of an erotic fantasy, and Nefertiti's winking gesture could be a demonstration of a private relationship between the creator and his creation. (See Figure 7) In this sense Sutherland's winking Nefertiti is comparable to the famous early cartoon character *Betty Boop*, invented in 1930.[262] Betty Boop was famous for her flirtatious wink and the phrase "made of pen and ink, she will win you with a wink" that introduced Betty's cartoons.[263]

[262] Emmons and Kassem, "*Architect-Computer Symbiosis*." 53
[263] Patrick Maynard, *Drawing Distinctions* (Ithaca, NY Cornell University Press, 2005), 88.

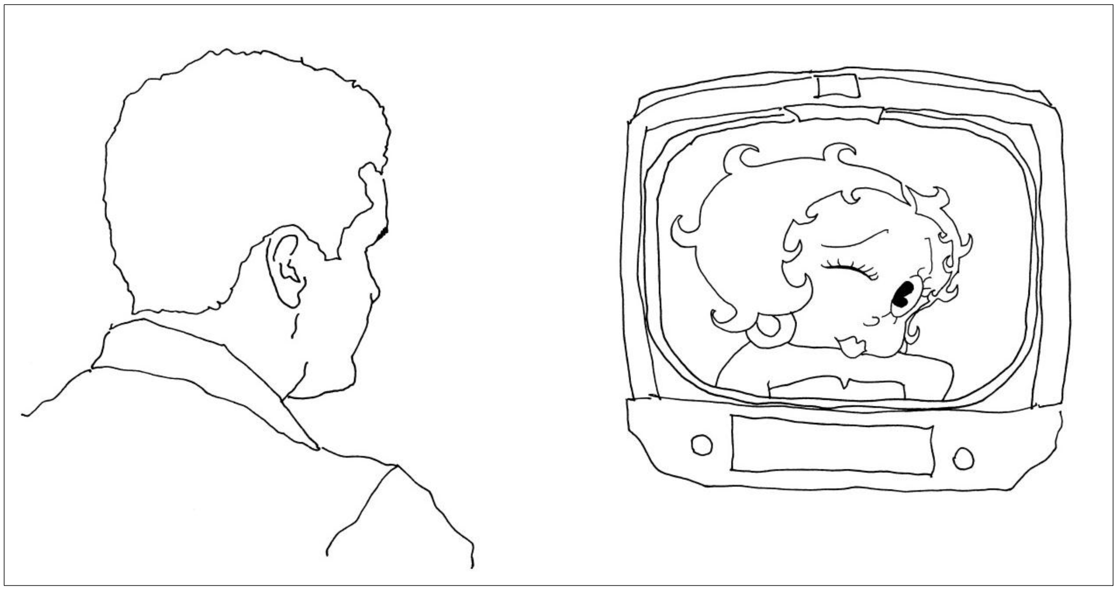

Figure 8: Betty Boop, she can win you with a wink through Sketchpad's CRT window. (Drawn by the author)

The anthropologist Clifford Geertz explained that the main difference between a twitch and a wink is that although the physical act may look identical, a wink is a cultural gesture, meant to communicate a private and conspiratorial message to another person. Geertz stated: “The winker is communicating, and indeed communicating in a quite precise and special way: (1) deliberately, (2) to someone in particular, (3) to impart a particular message, (4) according to a socially established code, and (5) without cognizance of the rest of the company.”[264]

Geertz described the wink as a “thick description” that carries meaningful structures that are necessary for its production, perception, and interpretation.[265] Here, the winker understands the cultural meaning behind the wink; however, these cultural gestures are: “fictions, in the sense that they are something made, something fashioned – the original meaning of fictio.”[266] Nefertiti winking at Sutherland may be interpreted as imparting a shared knowledge of the future of Sketchpad, both in giving birth to graphical computer-aided design systems, and proclaiming the symbiotic partnership between the computer and human beings that would emerge throughout the late twentieth century.

[264] Clifford Geertz, *The Interpretation of Cultures: Selected Essays* (New York: Basic Books, 1973).
[265] Ibid, 7.
[266] Ibid, 15.

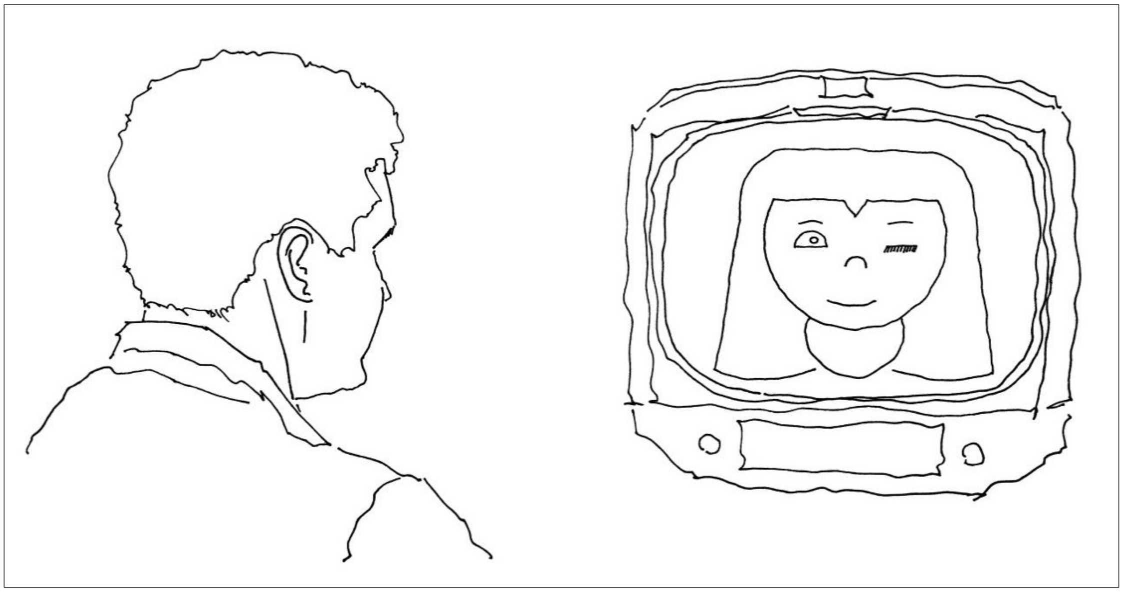

Figure 9: Winking Girl Nefertiti shares a private relationship with her inventor. (Drawn by the author)

Through Sketchpad's window, Sutherland had found a way to give life to his fantasies visually. In a 1907 lecture presented by the psychologist Sigmund Freud entitled *Creative Writers and Day-dreaming*, the father of psychoanalysis believed that "every child at play behaves like a creative writer, in that he creates a world of his own."[267] Both child and adult engage in their respective activities seriously, and both are able to separate between the real from the imaginative. However, the difference between the child and the adult is that the child connects "his imagined objects and situations to the tangible and visible things of the real world,"[268] so that, for instance he imagines his car seat as a vehicle in itself that zooms along the road. In contrast, the adult hides his play out of shame, and keeps his fantasies to himself.

Freud believed that, as people grow up, they substitute the childhood pleasure of play with fantasies. Rather than deriving pleasure from childhood play, the adult "builds castles in the

[267] Servulo Figueira, Peter Fonagy, and Ethel Spector Person, *On Freud's Creative Writers and Daydreaming*, (Yale University: Karnac Books, 2013), 5.
[268] Ibid, 143.

air and creates what are called daydreams."[269] Moreover, young male fantasies are often an expression of "ambitious wishes come to the fore clearly enough alongside of erotic ones."[270]

In the early 1960's, during the Sketchpad invention, Hollywood movie stars often portrayed Egyptian royalty. For instance, in 1961 the beautiful American actress Jeanne Crain performed in the leading role of Nefertiti in the movie *Nefertiti, Queen of the Nile.*[271] And in 1963, the beautiful American actress Elizabeth Taylor performed in the leading role of the Egyptian queen, *Cleopatra.*[272] In 1935, the film director and screenwriter William de Mille believed that Americans maintained a love-hate relationship with movie stars, because audiences connected with movie stars at an emotional level and with a special sense of intimacy. De Mille observed that: "people feel a peculiar sense of ownership in these romantic figures they have created."[273]

According to Hookway, the theory of the interface is a theory of culture.[274] As he stated: "To use an interface is to participate in culture."[275] In Sketchpad, the interface extends from the relation that holds the human user and computer together, towards ideas of control and power. Here, the interface demands of the entities entering into relation with it, a kind of surrendering of the self.

The Sketchpad interface comes into being as the human user actively works with it, and its essential power lies in the symbiotic partnership between human and machine. Hookway believed that: "What most define the interface are the processes by which it draws together two or more otherwise incompatible entities into a compatibility within which they become available to one another to the extent allowable within the operation of the interface."[276] The Sketchpad interface marks the limits of a specific cultural space, within which a specific set of relations may occur. It presents itself in space and in time, and its effects are understood and treated within culture, particularly the relation between human beings and technology. Thus, there is a

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[269] Ibid, 145.
[270] Ibid, 147.
[271] Jeffrey Richards, *Hollywood's Ancient Worlds* (London: Bloomsbury Academic, 2008), 146.
[272] Kathryn Dixon, *Elizabeth Taylor* (Charlotte: Taj Books, 2014), 90.
[273] Steve J. Ross, *Hollywood Left and Right: How Movie Stars Shaped American Politics* (Oxford: Oxford University Press, 2011), 5.
[274] Hookway, *Interface*, 15.
[275] Ibid, 16.
[276] Ibid, 17.

connection between Hollywood movie stars, art and culture,[277] and Sutherland's use of a popular American figure to express technology demonstrated the increasing importance of computer technology within American culture.

Power over Sketchpad

The relationship between the interface and the wielding of power is a concept that can be found in Roman mythology, particularly embodied in the figure of Janus.[278] This figure was the spirit of doors and thresholds and is depicted with two faces set in opposing directions, often holding a key in his hand. Like his namesake that was chosen for the first month of the year in the Roman calendar, Janus was the god of all beginnings and all endings. Janus's two faces represented his ability to look at the same time at both entrances and exits, and to look into the past and the future.[279]

The characteristics of Janus are parallel to the characteristics of the Sketchpad interface, whose visage also watches at the same time in two directions, at once towards the human user and towards the machine. Like the Sketchpad interface, Janus's domain of control is over the passage between two separate entities. The dominion of Janus extends to the threshold of conflicts, between war and peace, and the dominion of the Sketchpad interface extends to the threshold of conflicts between two incompatible entities, the human and the machine. Hookway argued that: "Power is exerted in the drawing together of once incompatible states into compatibility. Here the agency of power works alongside and within its subject, in part enabling it by rendering the properties of another distinct state of being available for its use, and in part confining it within the processes of its operation."[280]

In the Sketchpad system, control takes place within the interface and in the relationship of the interface with the entities external to it, human and machine. The external power exerted

[277] Camille Paglia, *Sexual Personae* (New Haven: Yale University Press, 1990), 29.
[278] Hookway, *Interface*, 19.
[279] Ibid, 19.
[280] Ibid, 23.

by the Sketchpad interface, as a condition that faces, is directed toward establishing compatibility, so that lines of communication may be established.

The concept of the power of the creator giving life to his creation can be found in the narrative poem *Metamorphoses* by the Roman poet Ovid, in which Pygmalion was a sculptor who fell in love with a statue of a woman he had carved out of ivory. (See Figure 10) In the narrative, Pygmalion's statue becomes human under her creator's touch, and like the sculptor Pygmalion, the user of Sketchpad becomes a sculptor whose statue is sculpted through the cathode ray tube. Licklider believed that:

> The artist or craftsman may work through a computer into his traditional medium. One can imagine a sculptor, working with a Roberts Wand instead of a chisel,[281] shaping a graphically displayed computer-based model instead of a block of stone. He would work on the model until satisfied with it … one can imagine, also, that many artists and craftsmen will resist or react against such a departure from traditional procedures. Is the important thing to achieve the envisioned form, to achieve the envisioned form in stone, or to achieve the envisioned form in stone with a hammer and chisel? The basic notion is applicable, of course, to painting as well as sculpture.[282]

Licklider goes on to explain that: "The computer can hold the sculpture in its memory and display it in three dimensions continually or upon request."[283] These dimensions can be used at a later time to recreate the same sculpture from stone or from another material or media.[284]

Like Licklider, Coons stated that: "It will not be long before the designer can literally do sculpture with a computer. He will be able to draw three-dimensional configurations as complex as the human figure. The computer will then have an internal structuring of information so precise" that it would be able to reproduce it with precision.[285] Converting information about a drawing into a digital file that can be used to reproduce a copy of it is not a new concept. Alberti

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[281] Licklider is referring to the Lincoln Wand that Lawrence G. Roberts invented as an improvement over the light pen to be used with the TX-2 computer at MIT's Lincoln Laboratory. Roberts Wand was an ultrasonic position-sensing device that was designed to allow a computer to determine periodically the x, y, and z coordinates of the tip of a pen-sized wand. Lawrence G. Roberts, "The Lincoln Wand," in Proceedings of the November 7-10, 1966, fall joint computer conference (San Francisco, California: ACM, 1966), 223.

[282] J. C. R. Licklider, "User-Oriented Interactive Computer Graphics," in *Proceedings of the ACM/SIGGRAPH Workshop on User-oriented Design of Interactive Graphics Systems* (Pittsburgh, PA: ACM, 1977) 95.

[283] Ibid, 95.

[284] Ibid, 95.

[285] Coons, "*Computer-Aided Design*."12.

also recognized the effectiveness of this method in his own works. In his treatise *On Sculpture*,[286] in 1436, Alberti translated the human body into a list of three-dimensional coordinates.[287] The list of coordinates produced was used to make a replica of the original body in any desired scale.[288] Sketchpad's symbiotic system demanded that this computer became human-like under her creator's touch, and the face of this human-like creation was the winking-girl Nefertiti.

Figure 10: Drawing after Jean-Leon Gerome's Pygmalion and Galatea, c.1890. (Drawn by the author)

[286] Leon Battista Alberti, *On Painting and on Sculpture: The Latin Texts of De Pictura and De Statua*, trans. Cecil Grayson (London: Phaidon, 1972).

[287]The hardware Alberti used to derive these coordinates was a revolving instrument that was pinned to the head of a statue. This instrument was called a "Definer" and consisted of three parts: an orizzonte, a Linda and a plumb line. To measure the proportions of the parts of the statue, Alberti fastened the orizzonte on the head of the statue so that the entire disk could revolve about its center. He then placed the Linda in the first unit of the disk then turned the disk around until the plumb line struck an extended part of the body. Gadol, *Leon Battista Alberti: Universal Man of the Early Renaissance*, 78.

[288] Mario Carpo, *The Alphabet and the Algorithm* (Cambridge, Mass.: MIT Press, 2011), 55.

Sketchpad and the Female Gender

In classical antiquity, one of the most familiar legends surrounding the origin of drawing and sculpture describes the tracing of the outline of someone's shadow,[289] thrown onto a surface by candlelight. Pliny the Elder, in his treatise titled *Natural History*, tells the story of the daughter of a potter from Corinth named Butades (in French Dibutade).[290] Dibutade's daughter expressed the emotion of love through drawing.[291]

Dibutade's daughter drew the outline on a wall of the shadow of her lover's face cast by the light of a lamp. Her lover was soon to leave, and the drawing was made to maintain a memory of him for her.[292] As Pliny described:

> Butades, a potter of Sicyon, was the first who invented, at Corinth, the art of modeling portraits in the earth which he used in his trade. It was through his daughter that he made the discovery; who, being deeply in love with a young man about to depart on a long journey, traced the profile of his face, as thrown upon the wall by the light of the lamp. Upon seeing this, her father filled in the outline, by compressing clay upon the surface, and so made a face in relief, which he then hardened by fire along with other articles of pottery.[293]

In the Sketchpad system, the gender that Sutherland gave to the cartoon faces looking back at him from the computer window was female. This expression of technology through the female gender can also be found in the 1927 German science fiction film, *Metropolis.* In that film, technology is represented in the form of a female robot. The creator of this robot modeled her exterior skin to look exactly like the virtuous woman in the film, Maria. However, unlike the human Maria that is good and decent, the human-like Maria is deceitful and manipulative. In the film, this false Maria, who is referred to as the *Whore of Babylon,* uses the gesture of the wink to

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[289] Booker *A History of Engineering Drawing*, 1.
[290] Martin Calder, *Encounters with the Other: A Journey to the Limits of Language through Works by Rousseau, Defoe, Prévost and Graffigny* (Amsterdam: Rodopi, 2003), 256.
[291] David F. Krell, *Purest of Bastards: Works of Mourning, Art, and Affirmation in the Thought of Jacques Derrida* (PA: Pennsylvania State University Press, 2010), 51.
[292] Booker, *A History of Engineering Drawing*, 1.
[293] Pliny, *The Natural History of Pliny*, trans. John Bostock and Henry T. Riley (London: H. G. Bohn, 1857), 283.

collaborate with the man she was created to serve, then uses her sexuality to entice men to follow her to their destruction. (See Figure 11)

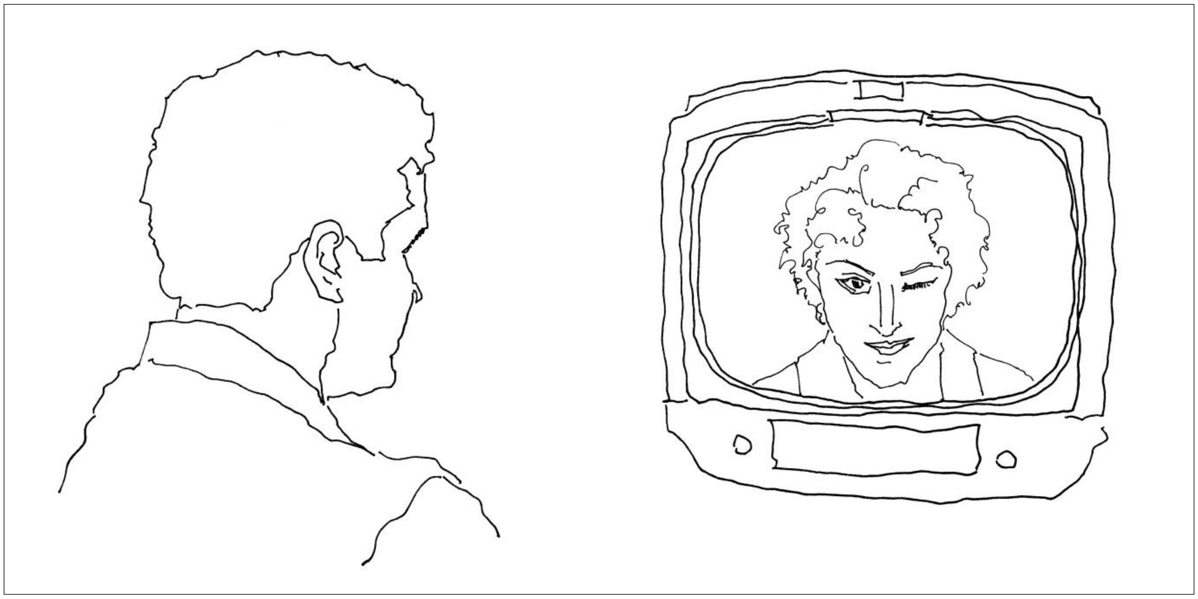

Figure 11: Fake Maria, she can win you with a wink through the CRT window. (Drawn by the author)

Another example of a film that represents the machine as an evil agent swallowing human workers is Charlie Chaplin's 1936 film *Modern Times.* (See Figure 12) Chaplin's film is a: "cautionary tale about the dangers of the industrial age and the powerful machines that threaten, quite literally, to consume the worker and to render the manager obsolete."[294]

[294] Bruce Grenville, *The Uncanny: Experiments in Cyborg Culture* (Vancouver Art Gallery: Arsenal Pulp Press, 2001), 26.

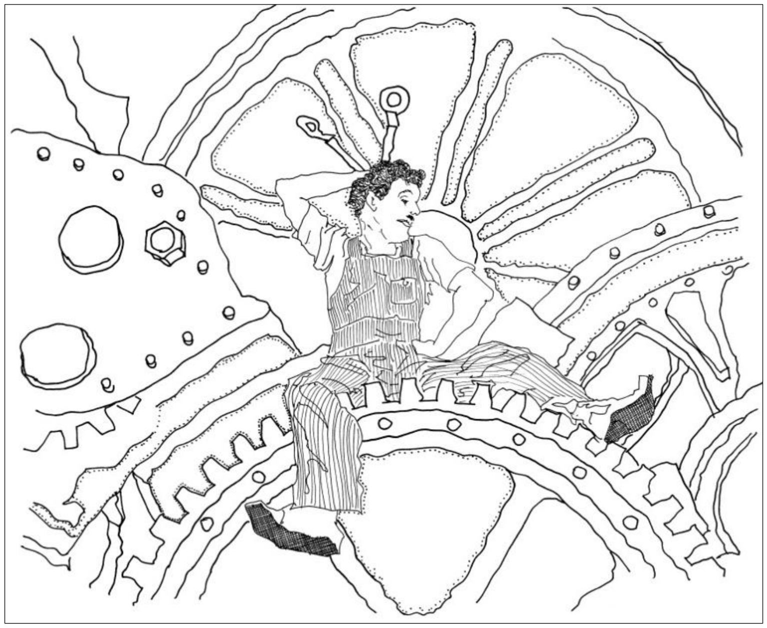

Figure 12: Charlie Chaplin is the factory worker that is swallowed by the machine. (Drawn by the author)

However, in the film *Metropolis*, the distrust of the machine industry is communicated to the viewers through the use of feminine sexuality. And this approach was not unusual. Many researchers argue that: "The female body and female sexuality have been used to represent broad cultural anxiety surrounding the allure and the threat of the machine."[295] This gendering of technology allows its 'otherness' to be identified, and its potential dangers removed.[296]

[295] Ibid, 22.
[296] Emmons and Kassem, "*Architect-Computer Symbiosis."* 53.

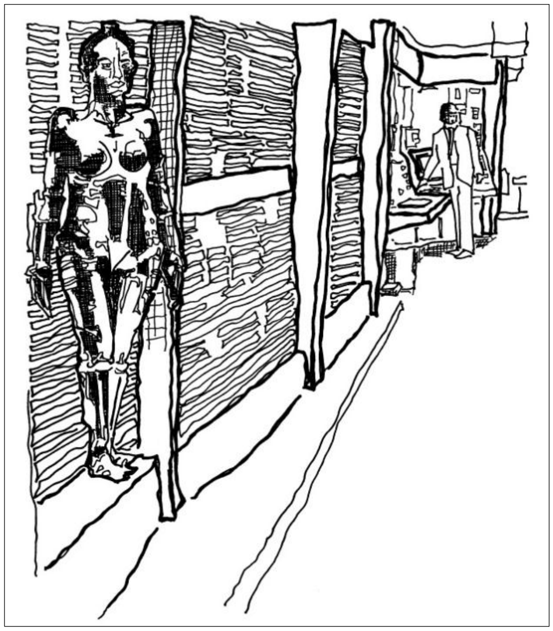

Figure 13: The TX-2 computer and Fake Maria's threat hidden from Sutherland. (Drawn by the author)

The construction of the computer-aided design system with a woman's face acknowledges this growing presence of the machine in culture. Within Sketchpad's system is a desirable object, a subject of visual pleasure: "But because the female body is the subject of desire, it is also a threat to the solidarity and unity of the patriarch. The resulting confusion between desire and repulsion may be read as a simple manifestation of the broader cultural confusion regarding the new and changing role of the machine."[297]

[297] Grenville, *The Uncanny: Experiments in Cyborg Culture*, 25.

Consequently, as Sutherland faces a winking Nefertiti on the Sketchpad interface, the interface becomes the means by which the human user encounters its technological other, "through a mediation that already carries with it the conditions of its human use. As a corollary, the human encounter with technology always involves a mirroring."[298]

Therefore, the Sketchpad interface made it possible for Sutherland to encounter a partial aspect of the technological 'other' in the form of an active intelligence that was rendered compatible within that interface. In this context, a winking Nefertiti may be viewed as a projection of human intelligence onto the machine. The Sketchpad interface enabled a gathering inward and a looking outward that was confined within the system's space.

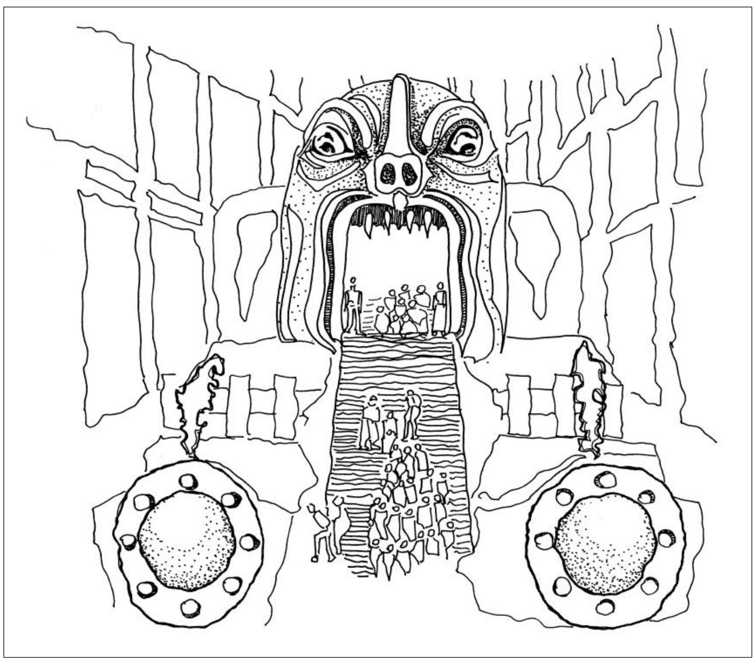

Figure 14: Guards march human sacrifices up the steps and into the machine's fiery mouth from the film Metropolis. (Drawn by the author)

[298] Hookway, *Interface*, 44.

Chapter Six: Freehand Sketching in Sketchpad

Freehand sketching is a valuable drawing component in the development of design concepts in both architecture and engineering disciplines. The etymology of the word *Sketchpad* can be derived from the words *sketch* and *pad*. The origin of the word *sketch* is from the Greek *skhedios* and is used to indicate a rough or unfinished drawing often made to assist in making a more finished picture, rendering it a brief description and an unfinished version of any creative work.[299] The origin of the word *pad* refers to the German *pad* of sole of the foot; here the word *pad* is a reference to a number of sheets of blank paper fastened together at one edge, used for drawing.[300]

Unlike the *Sketchbook* that is defined by the *Harvard University Art Museums* in their *Guide to Drawing Terms and Techniques* as "a book that contains drawing paper for sketches,"[301] the term *Sketchpad* is commonly understood as a binding together of many sheets of paper without a cover. Therefore, *Sketchpad* can be understood as many sheets of paper that are bound and used to create a rough preliminary drawing that is continually refined and developed through the activity of drawing on layers of a physical material by leaving a residue of pigment with the guidance of pressure generated from the drafter's hand.

Sutherland's Sketchpad led to the development of the field of *sketch-based interfaces and modeling* that enabled the "users [to] interact with a computer through sketching, a simple, yet highly expressive medium.[302] In this way, by: "Using a light pen, a user could draw rough shapes composed of lines and circles on a virtual sheet of paper."[303]

In an interview with Johnson, he described Sketchpad's display device as a window, and in the interview, he asked the viewer to imagine the computer as a fixed sheet of paper behind this window. The Sketchpad window, with its fixed square dimension, measured approximately

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[299] J. A. Weiner Simpson, *The Oxford English Dictionary* (New York: Clarendon Press, 1989).
[300] Ibid.
[301] Jo Davies and Leo Duff, *Drawing the Process* (Bristol: Intellect Books, 2005), 71.
[302] Joaquim Jorge and Faramarz Samavati, *Sketch-Based Interfaces and Modeling* (London: Springer Science & Business Media, 2010). Foreword Professor of Computer Science Andries van Dam.
[303] Sharon Oviatt, *The Design of Future Educational Interfaces* (Oxon: Routledge, 2013), 135.

seven square inches on each side and the computer imaginary fixed paper measured approximately two square miles.[304] These dimensions were determined according to the technology of the CRT monitor and the TX-2 computer memory that operated Sketchpad.

Although Sutherland called his invention Sketchpad, the new drawing pad left out many important aspects in the drawing and design process. For instance, Sketchpad's imaginary single sheet of paper eliminated the reiterative process, including the sketch, the overlay transparent paper, the re-sketch, and the revision. This process, which exists in traditional drawing, is repeated several times "until the drawing and the vision touch one another."[305] What is clear is that certain functions of the freehand sketching process that are made in sketchbooks cannot be replaced by those made on a computer. Sutherland recognized the inferiority of the computer display to the paper, stating that: "When compared with a drawing on paper, the pictures presented by today's computer display equipment are sadly lacking in resolution."[306] Sketchpad lacked the "quality of palimpsestin the sketchbook,[307] (where layers of forms and ideas overly layers, and traces of partially erased layers rise to the surface and become part of the form)."[308]

The inducement to use freehand sketching in a computer drawing, despite the absence of the reiterative quality in a computer screen, was provided by the novel notion that freehand sketching did not require the drafter to have any artistic talent or a steady hand in drawing.[309] Sutherland believed that sketching was an intuitive drawing technique that could be easily converted into computer language. Sutherland's sketch of a winking girl's face in his dissertation did not express the actual geometry of the human face; instead it represented the visual appearance of a human, made of lines and circle segments as a child might draw it.[310]

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[304] Morash, "*Computer Sketchpad*."
[305] Susan Piedmont-Palladino, *Tools of the Imagination: Drawing Tools and Technologies from the Eighteenth Century to the Present* (New York, N.Y.: Princeton Architectural Press, 2006), x.
[306] Robert F. Sproull and Ivan E. Sutherland, "A Clipping Divider," in *Proceedings of the December 9-11, 1968, fall joint computer conference, part I* (San Francisco, California: ACM, 1968), 765.
[307] Palimpsest is a term that originated from the Greek 'to rub again,' meaning that a used manuscript has twice been cleaned and used again for another work. Keith Elliott and Ian Moir, *Manuscripts and the Text of the New Testament* (Edinburgh: T & T Clark, 1995), 12.
[308] Douglas Gittens, Angela Bartram, and Nader El-Bizri, *Recto Verso: Redefining the Sketchbook* (Burlington: Ashgate Publishing Company, 2014), 39.
[309] *Timothy E. Johnson, "Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*" (Massachusetts Institute of Technology, 1963), 15.
[310] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 133.

As the art teacher Gerhard Gollwitzer wrote in his book titled *Joy of Drawing*: “Talent is a slippery concept.”[311] While drawing is arguably an art form that demands some degree of talent,[312] the talented and untalented can sketch and the practice of sketching begins from childhood. To illustrate this point, in a chapter titled *Freehand Sketching* from his book titled *Graphics*, Coons gave examples of sketches of a house and a drinking glass made by both a child and an adult.[313] (See Figure 15)

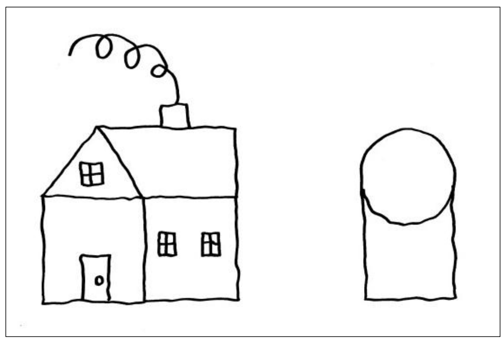

Figure 15: Drawing after Steven Coons' house and drinking glass. (Drawn by the author)

Coons believed that the objective of the sketch was to give the “visual appearance” of the object and not the object’s actual geometry.[314] For example, if a child were asked to draw a hand, the primary impulse would not be imitating the visual model of a hand but rather from the idea of a hand as having five fingers: “The child would first and foremost grasp the ‘fiveness’ of a hand, and represent it graphically in an abstract way to caring little about the look of the drawing but taking great pains to be certain that the correct number of digits are present.”[315]

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311 Gerhard Gollwitzer, *The Joy of Drawing* (New York: Gramercy Pub Company 1961), 100.
312 Betty Edwards, *Drawing on the Artist Within* (New York: Simon & Schuster, 2008), 5.
313 Rule and Coons. *Graphics*, 68.
314 Ibid, 68.
315 Thomas W. Schaller, *The Art of Architectural Drawing: Imagination and Technique* (New York: Van Nostrand Reinhold, 1997), 36.

Coons believed that: “When an association is first made in the mind when we get the first glimmer of an idea it is usually vague and not clearly perceived. It is at this early stage in the creative process that mankind has learned to use the sketch and the written symbol as aids to the thinker’s memory and imagination.”[316]

Capturing fleeting dreams with the aid of drawing is another aspect that Sketchpad was not able to fulfill. The visual artist Man Ray[317] recognized the limitation of technology as an aiding tool in capturing dreams and expressed his thoughts in his famous statement: “I paint what cannot be photographed, and I photograph what I do not wish to paint … if it is something I cannot photograph, like a dream or a subconscious impulse, I have to resort to drawing or painting.”[318]

In his book titled *Why Architects Still Draw*, Paolo Belaerdi, an architect, poet and professor at the Department of Civil and Environmental Engineering at the University of Perugia, interpreted Man Ray’s meaning that: “only drawing allows us to express our dreams” and that “those who cannot dream are not able to draw either… only the dreamer-slash-drawer … is able to communicate emotions as well as information.”[319]

In his essay titled *Architectural Encounters between Material and Idea*, the architect and architectural theorist Paul Emmons argued that: “Design is often approached as a process of conceiving an architectural form that is later inserted onto pliant material … During design, idea is revealed within, not prior to or in spite of material.”[320]

Renaissance artists were aware of the importance of the bodily act of drawing and advocated that the apprentice should learn the art of drawing through a bodily habit. Michelangelo believed that the repetitious bodily practice of drawing was fundamental to the

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[316] Rule and Coons. *Graphics*, 66.
[317] Man Ray (1890-1976) was an American photographer, artist, filmmaker, poet and surrealist. Patrick Bade, *Man Ray* (New York: Parkstone International, 2005), 5.
[318] Paolo Belardi. *Why Architects Still Draw* trans. Zachary Nowak (Cambridge, Massachusetts: The MIT Press, 2014), 41. Quoted from “Man Ray – Interview in Camera,” Paris; reprinted in *Man Ray: photographe,* ed. Philippe Sers (Paris: Centre Georges Pompidou, 1981).
[319] Ibid, 42.
[320] *The Material Imagination: Reveries on Architecture and Matter*, (Burlington: Ashgate Publishing Limited, 2015), 89.

development of good drawing skills. In a note to an apprentice, Michelangelo wrote: "draw Antonio, draw Antonio, draw and do not waste time."[321]

Another example of an artist who understood the "performative" aspect of drawing and expressed it in his art was the painter Paul Klee.[322] Klee's drawings revealed the "bodily thought that emerges between artist and material, which grows stronger through repetition and experimentation."[323] In the opening of his *Pedagogical Sketchbook* that was published in 1900, Klee described "a line as a point going for a walk."[324] Klee stated: "An active line on a walk, moving freely, without a goal, a walk, for a walk's sake. The mobility agent, is a point, shifting its position forward."[325]

Coons recognized the changes that technology would have on designers, but believed that the changes brought by new computer drawing tools would be a good thing. As he stated: "Our intellectual tools influence to a very great extent the form and scope of our intellectual works. It is quite certain that when the computer replaces pencil and paper in this very real way, it will bring about a truly miraculous change in man's intellectual potential."[326]

Draw Sketchpad, draw and do not waste time.

Sutherland's new lines were drawn directly onto the computer's screen as if that screen was a sheet of paper, and the drawing tool was a fountain pen. The computer scientist Alan Kay stated: "I don't know who first made the parallel between programming a computer and using a tool, but it was certainly implicit in Jack Licklider's thoughts [referring to man-computer

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[321] Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004), 98.
[322] Paul Klee (1879-1940) was a Swiss-German painter and poet. Sabine Rewald, *Paul Klee: The Berggruen Klee Collection in the Metropolitan Museum of Art* (New York: Metropolitan Museum of Art 1988), 12.
[323]Paul Emmons and Carolina Dayer, "*Toward Perfomative Architectural Drawing: Paul Klee's Enacted Lines."* Essay in Marcia Feuerstein and Gray Read, *Architecture as a Performing Art* (England: Ashgate Publishing 2013), 46.
[324] Ibid, 47.
[325] Paul Klee, *Pedagogical Sketchbook*, trans. Sibyl Moholy-Nagy (New York: Frederick A. Praeger 1953), 16.
[326] Coons, "An Outline of the Requirements for a Computer-Aided Design System." 302.

symbiosis] … Sutherland's Sketchpad became the exemplar to this day for what interactive computing should be like."[327]

Coons was aware of the material aspect of drawing tools involved in sketching, the movement of the body during the drawing process, the tremors of the hand that creates different line thickness, and the trail left by the pencil or pen on the paper.[328] Sutherland believed that certain aspects in traditional drawing that do not support utilizing the capabilities of the computer should be left out, while aspects that support a mimicking of traditional drawing technique without obstructing the role of the computer in drawing should be preserved.

One of the most difficult challenges to developing the Sketchpad system was replacing the pen and paper with the light pen and computer window. According to Johnson:

> Research began by attempting to throw out the concept of pen and paper (this proved to be the most difficult step). Realizing the digital computer allowed a new type of graphical communication, the problem lay in discovering it. The new communication method had to be general, simple to use, and take advantage of the logical power offered by the digital computer.[329]

Sketchpad gave the illusion of drawing instantly on the computer window without recognizing the computer as a symbiotic partner in the act of drawing. In a Sketchpad drawing, there are two active entities in the drawing process, human and the computer. While the human's role in the computer drawing is unconcealed, the computer performs independent tasks discreetly in its *Central Processing Unit* and delivers the results to the human user through the Sketchpad window.

As computer hardware was being developed and improved, the lag time between giving a command to the computer and receiving results decreased, making the human user less and less aware of the computer as a partner in the drawing process. According to Mitchell:

> Beginning with I. E. Sutherland's very important pioneering Sketchpad system, an enormous amount of effort has been devoted to development of graphic input techniques that enable a user to sketch on the surface of a refreshed CRT using a light-pen. The effect of direct sketching is an illusion. What really happens with these systems is that coordinate data is taken from the pen, and an appropriate graphic display is instantaneously produced as a result. Thus for example, an object can be made to appear

[327] Allen Cypher, *Watch What I Do : Programming by Demonstration* (Cambridge, MA: The MIT Press, 1994), Foreword by Alan Kay.
[328] Rule and Coons. *Graphics*, 69 .
[329] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." 15.

> as if dragged around the screen by a light pen, by means of very rapid regeneration of the object at successive locations of the pen.[330]

Rather than an inscription tool for drawing,[331] the light pen operated as a communication device with the computer. The process of drawing on the computer window became even more removed from the illusion of traditional drawing with the creation of the three-dimensional extension of the Sketchpad system. According to Johnson: "The method used in Sketchpad III to draw directly in three dimensions is simple and straightforward. However, this deceptively simple approach was not immediately evident at the outset of Sketchpad III development."[332]

Unlike the traditional pencil that was, in a sense, a part of the drafter himself and an extension of the power of his hand,[333] the light pen eliminated the material aspect of drawing, resulting in a disconnect between the hand held device and the drawing surface. Unlike the seamless contact between the pen and paper in the traditional drawing process**,** there is a gap between the tip of the light pen and the drawing in the Sketchpad system. The inventors of Sketchpad were aware of the challenges of using the light pen as a drawing tool to replace the ink pen. According to Johnson: "At that time, September 1961, the light-pen was available, but considerable skepticism existed about its use as a precision drawing device. A project spokesman allegedly noted, drawing with a light-pen is like trying to write your name on a wall fifty feet away with a pistol."[334]

Describing the experience of drawing on the Sketchpad window using the light pen as similar to the experience of trying to write one's name on a wall with a pistol, emphasizes the distance between the tip of the light pen and Sketchpad's drawing surface. This description illustrates the difficulties of using an electrical pen to create electrical drawings in comparison with the ease of the traditional methods of drawing using a pen or a pencil on paper. Therefore, the promise of an intuitive drawing tool that could replace the pencil was not realized.

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[330] Mitchell, *Computer-Aided Architectural Design,* 326.

[331] The concept of inscription focuses on the materiality of representational tools. Drawing inscriptions are characterized by three properties: "mobility, immutability and two-dimensionality." Ursula Klein, *Tools and Modes of Representation in the Laboratory Sciences* (Dordrecht, Netherlands: Kluwer Academic Publishers, 2001). 96.

[332] Johnson, "Sketchpad Three Dimensional Graphical Communication with a Digital Computer." 15.

[333] Paul Emmons, *The Lead Pencil: Lever of the Architect's Imagination.* An essay from: Piedmont-Palladino, Tools of the Imagination: Drawing Tools and Technologies from the Eighteenth Century to the Present, 31.

[334] Johnson, "*Sketchpad Three Dimensional Graphical Communication with a Digital Computer*." 15.

The consequence of this disconnect is obvious in computer-aided architectural design tools that consequently evolved from Sketchpad. As Emmons stated:

> Since the physical aspects of building are best grasped through the materiality of the architectural drawing, how can computer-generated drawings encourage this connection? In computer drawing, the digits of the hand no longer have tactile connection to the production of the drawing; touching keys is physically unrelated to the images that appear on the screen.[335]

Other possible alternatives to the light pen were explored, such as attaching a manually directed stylus to a pantograph that drove two shaft encoders, where the encoders would determine the two-dimensional position of the pen. Another approach involved the use of a manual joystick device that would determine the two-dimensional position through the movements of the hand. These alternative approaches were dismissed because the precision of these drawings depended on the drafter having a steady hand and some artistic skills, and these alternative drawing approaches were more related to the continuation of the pen and paper concept of drawing rather than to the optimization of the potentials of the computer as a new drawing tool.[336]

Negroponte believed that an effective human-computer interface design included the computer understanding incomplete and ambiguous thoughts through quick freehand sketches created by a designer in the early stages of the design process, rather than complete and consistent drawings of a complex and finished design.[337] Subsequently, Negroponte's work focused on understanding "sketching behavior" and a "person's graphical intent." Rather than create drawings for other human perceivers to understand, the objective of the drawing was to make the computer understand the movement of the drafter's hand and thereby the intention behind the hand gesture.

The idea was that if the computer could correctly interpret the drafter's intention behind the hand movement it would be able to produce the desired line on the computer's display. As Negroponte stated:

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[335] Piedmont-Palladino, *Tools of the Imagination: Drawing Tools and Technologies from the Eighteenth Century to the Present*, 35.
[336] Johnson, *"Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*."
[337] Negroponte *Being Digital*, 104.

> If a user slowly drew a gentle and seemingly purposeful curve, the computer presumed he or she intended it as such, whereas the very same shaped line, if quickly drawn, may well have been intended to be a straight one. If these two gentle curves were viewed after the fact, instead of while they were drawn, they could look exactly alike. The user's drawing behavior, however, indicated two totally distinct differences in intent.[338]

Furthermore, Negroponte believed that sketching behavior varied from one person to another because each person has a unique style of drawing. As a result, "the computer had to learn about the sketching style of each user."[339] The developments that followed the Sketchpad invention focused on programming the computer to recognize handwriting by adapting to the user's penmanship and recognizing sketched shapes.

Rather than viewing the sketching process in itself as a search into further insight in the design, researchers in the field of computer science were driven by enhancing the human-computer collaboration, thus: "The motivation for their research is the unexploited potential of computers to aid the sketching and visual idea generation process."[340] These computer science experts have described the sketch as "a special kind of sparse drawing, usually produced quickly in a manner peculiar to its creator." And that those sketches "can be considered as a means of externalization of ideas."[341] Emmons believed that:

> Notions of tools as extensions of the hand have been usurped by contemporary conditions of 'abstract machines' that absorb both human and instrument into larger functional systems. Systems such as computer drawing programs threaten to eliminate the material imagination in their production of simulacra.[342]

Robert Stotz, a member of the Electronic Systems Laboratory at MIT,[343] stated that: "The display scope and light pen form, so to speak, the paper and pencil of the designer, but they possess

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[338] Ibid, 104.
[339] Ibid, 105.
[340] Thomas Grechenig and Manfred Tscheligi, *Human Computer Interaction Vienna Conference, Vchci '93*, Lecture Notes in Computer Science (Berlin, Heidelberg: Springer-Verlag, 1993), 185.
[341] Ibid, 185.
[342]Paul Emmons, "The Lead Pencil: Lever of the Architect's Imagination." In *Tools of the Imagination: Drawing Tools and Technologies from the Eighteenth Century to the Present*, edited by Susan Piedmont-Palladino (New York: Princeton Architectural Press, 2007), 38.
[343] Thierry Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing* (Stanford, Calif.: Stanford University Press, 2000), 87.

some extremely useful additional properties which open a whole new expressive medium."[344] In his paper titled *Man-Machine Console Facilities for Computer-Aided Design* published in 1963, Stotz described the opportunities that the new light pen and display console hardware provided for the designer but recognized that using these new drawing tools would present their own new challenges in the "Computer-Aided Design problem."[345] Among these problems was the challenge of communicating the design to the computer; Stotz believed that the solution to this problem was in developing computer hardware that would: "Provide flexibility of input, particularly regarding the control of the displays and the interpretation of light pen actions."[346]

In a Sketchpad drawing, information about the appearance of the drawing and the links of the different parts of the drawing is stored in the computer. This stored information about the structure of the drawing allows the user to move various parts of the drawing using the light pen without disturbing the overall appearance of the whole.[347] Sutherland stated:

> Conventionally, of course, drawing is an active process which leaves a trail of carbon on the paper. With a computer sketch, however, any line segment is straight and can be relocated by moving one or both of its end points. In particular, when the button 'draw' is pressed, a new line segment and two new end points are set up in storage, and one of the line's end points is left attached to the light pen so that subsequent pen motions will move the point. The state of the system is then no different from its state whenever a point is being moved.[348]

While Sketchpad was described as a drawing tool that can replace the pen and pencil in the sketching process, it differed significantly from the traditional pen and pencil in its function as a drawing tool and its role in the process of creating a sketch. Sketchpad's hand held device went beyond creating line drawings to include communicating drawing intentions with the computer. In traditional drawing processes, the drawing is revealed to the human-user through the act of drawing itself and with the aid of the drawing tool. However, in the computer drawing, the drawing tool is used to bridge the gap between the human-user and the computer, and the drawing process is a form of educating the computer on how to represent a drawing.

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[344] Robert. "*Man-Machine Console Facilities for Computer Aided Design."* 323.
[345] Ibid, 323.
[346] Ibid, 323.
[347] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 8.
[348] Ibid, 102.

Sketchpad's Light Pen

The light pen was a descendant of the light gun that was developed in 1949 by the Whirlwind laboratory's technical director, [349] Robert Everett.[350] The light gun was used in the context of the *Semi Automatic Ground Environment* radar system, referred to as *SAGE*, and was used to select a specific blip on the radar screen for tracking.[351] The light gun went through a series of modifications that eventually led to the light pen.[352] Everett believed that the light pen was the first invention that connected a visual display to a computer.[353]

The light pen designed at Lincoln Laboratory was "a hand-held cylinder with a photocell mounted inside at one end and a wire leading back to the computer at the other end."[354] (See Figure 16) The light pen operated on the radar principle employed by the light gun and fulfills the drawing functions needed to create human-computer graphic communication.

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[349] Project Whirlwind was a high-speed computer that was developed at the Massachusetts Institute of Technology by the Office of Naval Research and the United States Air Force. R. R. Everett, "The Whirlwind I Computer," in *Papers and discussions presented at the Dec. 10-12, 1951, joint AIEE-IRE computer conference: Review of electronic digital computers* (Philadelphia, Pennsylvania: ACM, 1951), 70.
[350] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 86.
[351] Ibid, 86.
[352] Ibid, 87.
[353] Hookway, *Interface*, 149.
[354] Robert. "Man Machine Console Facilities for Computer-Aided Design," 323.

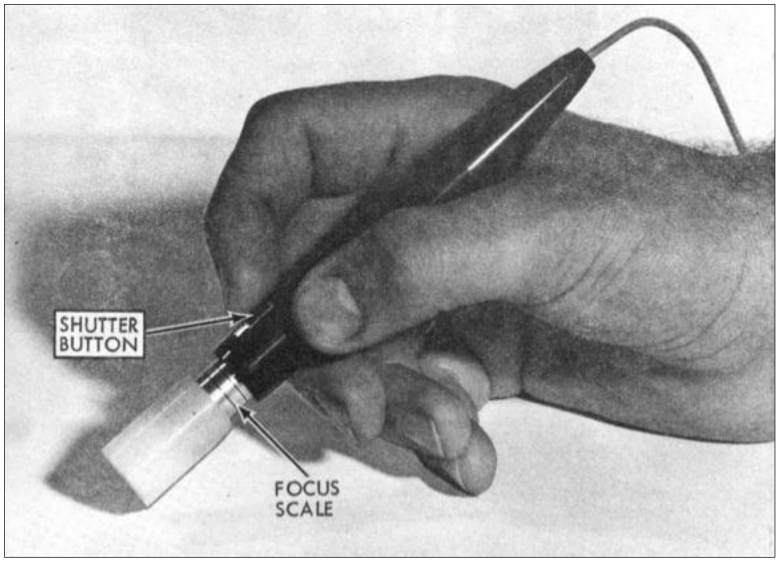

Figure 16: Light Pen, Ivan Sutherland, "Sketchpad: A Man-Machine Graphical Communication System" (Massachusetts Institute of Technology, 1963), 54. (By courtesy of MIT)

Stotz believed that: "The light pen can be used to simulate the 'drawing' ability of a real pen by having the computer program 'track' its arbitrary motion over the scope face."[355] Like the human operator and the computer that are imagined to be partnering entities in the design process, the light pen is in some instances also described as a separate entity in the design. Stotz stated that:

> The light pen also has the unique power of being able to identify points or lines to the computer. When used in conjunction with special buttons or knobs or keyboard input these 'identified' points or lines can be assessed in any number of ways. Solitary Points can be interpreted as special test points by the program, so that when these spots are 'seen' by the pen, the program branches.[356]

In addition to drawing, the light pen was used to perform other tasks in Sketchpad III, such as magnifying or reducing the drawing, rotating the drawing clockwise or counterclockwise, and forcing or relaxing the perspective by changing the convergence of the lines.[357]

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[355] Robert "Man-Machine Console Facilities for Computer-Aided Design." 324
[356] Ibid, 324.
[357] Timothy E. Johnson, "*Sketchpad III: A Computer Program for Drawing in Three Dimensions*" (S.l., 1963).350.

A group of psychologists led by Licklider guided Everett in the transition of the light gun to the light pen, and according to a member of this team, the psychologist William McGill, Licklider took pride in the role of psychology and his concept of man-computer symbiosis in its design.[358] “A great moment occurred when Robert Everett invented the light gun,” said McGill - a device that Licklider's team helped refine into the light pen. As he said:

> The idea was that you should give the operator a pen with a light sensitive device on it, so that he could put it over the target blip, press a button on the pen, and acquire the location of the target in the computer. It worked, and it would go on to be used in nonmilitary applications. As McGill said: Lick was always immensely proud of the light pen.[359]

Licklider may have been proud of the role he had in developing the components of interactive human-computer systems, but he was not particularity satisfied with the capabilities of the light pen and the vertical displays with which they were used. Licklider made the following statement concerning his development of the light pen, revealing his frustrations:

> The light pen evolved from the light gun, a pistol-like device of the early 1950’s, intended to identify a blip on a computer-based radar display. The operator aimed the barrel at the place where the blip was expected to appear and pulled the trigger. If the blip appeared and was seen by the photocell in the barrel, the gun sent the computer a pulse, and the computer could figure out the range and azimuth of the target from the scan pattern. But the barrel of the light gun was usually too fat, and the end of the barrel so occluded the blip that the operator often missed it when it appeared or thought he hit it when it did not appear. Light pens inherited the obesity of light guns. Even worse, the displays with which they were used were almost always oriented vertically. The result was to tire the users’ arms, to fail to take advantage of their years of experience with pens and pencils on horizontal surfaces, and to doom the light pen to an early grave.[360]

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[358] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*,108.
[359] Ibid, 108.
[360] Licklider,"*User Oriented Interactive Computer Graphics*." 94.

After the Light Pen – The Mouse

The light pen was an "established technology, but it was awkward. The user held the pen in the air in front of the display. After a few minutes of interaction, fatigue would set in."[361] Eventually, the problems associated with the light pen were partially resolved with the invention of Douglas Engelbart's mouse at Stanford University.[362] (See Figure 17) Engelbart and his Stanford Research Institute team demonstrated the invention of the mouse in 1968 at the Fall Joint Computer Conference in San Francisco in an event known as "The Mother of All Demos."[363] Engelbart's mouse was designed as an improvement over the light pen.[364] "Basically, the mouse function was the same as the light pen's in Sketchpad."[365] In the documentation for the first patent of the mouse filed in June 1967, Engelbart described his mouse device. As Engelbart stated:

> An X-Y position indicator control for movement by the hand over any surface to move a cursor over the display on a cathode ray tube, the indicator control generating signals indicating its position to cause a cursor to be displayed on the tube at the corresponding position. The indicator control mechanism contains X and Y position wheels mounted perpendicular to each other, which rotated according to the X and Y movements of the mechanism, and which operated rheostats to send signals along a wire to a computer that controlled the CRT display.[366]

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[361] I. Scott MacKenzie, *Human-Computer Interaction: An Empirical Research Perspective* (Amsterdam: Morgan Kaufmann, 2013), 6.
[362] Douglas Engelbart was the recipient of the ACM A.M. Turing Award in 1997, and received the National Medal of Technology and Innovation from President Bill Clinton in 2000. Engelbart joined the Stanford Research Institute in the 1960's. And at SRI, Engelbart founded the Augmentation Research Center, where he developed the computer mouse. DiDio Laura, "*Remembering Douglas Engelbart*," Commun. ACM 56, no. 9 (2013), 25.
[363] A. Frenkel Karen, "A Difficult, Unforgettable Idea," Ibid.52, no. 3 (2009). 21. Andries van Dam, a professor of Computer Science at Brown University, described Engelbart's clip as the "Mother of All Demos." Rosemary et al., "50 Years after: We May Think"; The Brown/MIT Vannevar Bush Symposium." 55.
[364] Hookway, *Interface*, 149.
[365] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 95.
[366] Douglas C. Engelbart. *X-Y Position Indicator for a Display System*. USA 1967.

Instead of typing commands, the human user could manipulate the mouse to control an on-screen cursor.[367] With the cursor positioned over a graphic image representing a command, the operator could select that particular operation by pressing and releasing a button on the mouse.[368]

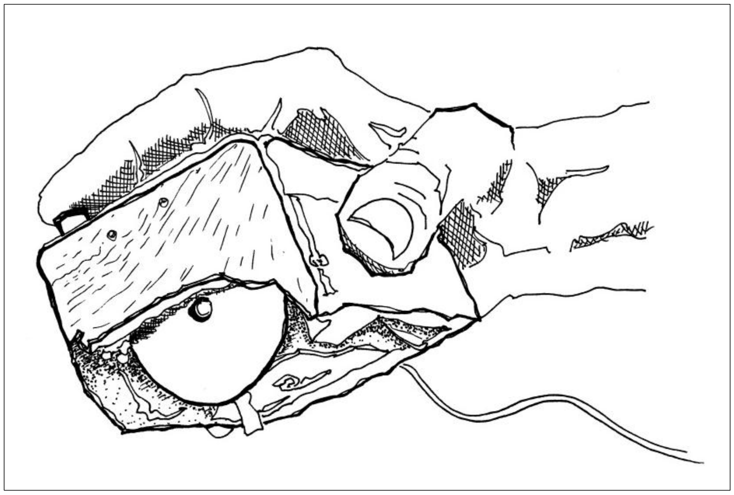

Figure 17: Drawing after Douglas Engelbart's Prototype of the first computer mouse. (Drawn by the author)

Initially, instead of a mouse, Engelbart thought of his invention as a "bug."[369] And Engelbart conceived of his "bug"[370] while he was attending a computer graphics conference.[371]

[367] The first prototype mouse included two potentiometers, large metal wheels that rotated as the devise was moved across a surface, and a selection button. MacKenzie, *Human-Computer Interaction: An Empirical Research Perspective*, 7.

[368] Ibid, 6.

[369] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 95.

[370] Engelbart's bug is comparable to Descartes' fly in that both insects are visualized to move in the Cartesian coordinate space. Rene Descartes was a French mathematician and philosopher who conceived of the Cartesian system of coordinates from a fly on the ceiling. Lounged on his bed, Descartes watched a fly drift near the ceiling, and Descartes thought, "If I could somehow measure, or describe, or identify, each point along that fly's path, I could write down an equation that would describe the arc." Watching the fly intently, Descartes realized that he could describe each point the fly touched exactly when it rested on the wall. Any point on the wall could be defined by measuring the location of the point from the ceiling, sidewall and back wall from the corner of the room. Kendall F. Haven, *Marvels of Math: Fascinating Reads and Awesome Activities* (Englewood, Colo: Teacher Ideas Press, 1998), 57.

[371] John Markoff, "Computer Visionary Who Invented the Mouse," *The New York Times* 2013.

As he said: “I remember sitting at some graphics conference and just feeling at a wall because everybody was talking and I’m not skillful getting them to listen to me. So a lot of times out of frustration I’d start talking to myself. I remember thinking, oh, how would you control a cursor in different ways?”[372]

The earliest mentioning of the bug, known later as the mouse, was found in Engelbart’s notes dated November 1963. There, he noted: “How about the earlier idea of counting impulses from X+Y displacement points? … Separate possibility of a “bug” instead of a stylus. [Referring to the light pen that was also referred to as a stylus] Bug being something that does not fall if you take hands off, just stay where you left it.”[373]

The mouse differed from the light pen in that it did not fall when the human operator let it go in comparison to the light pen that had to be returned to a resting place when it was no longer in use.[374] Another difference between the light pen and the mouse was that “the mouse design assumed that the surface on which the user moves the mouse is not a primary component of the system.”[375] In the Sketchpad system, the light pen mimicked the fountain pen and the TX-2 computer screen mimicked a pad, and the operator had to hold the light pen against the screen to make a drawing, as a result both light pen and screen were primary components of the system.

In contrast to the light pen, the mouse was independent from the computer screen and the operator could hold the mouse against any surface to make a drawing. In the documentation for the patent of the mouse, Engelbart stated that:

> The use of an indicator control [in his patent, Engelbart did not yet come up with the name *mouse* and instead refers to his invention as the *position indicator*] which rests firmly on a surface enables the operator to accurately maintain position with a minimum of muscle effort, since the indicator control remains stationary unless some force is applied to it. The use of relatively large position wheels having appreciable, even if small, moments of inertia, reduces jittering of the indicator control and promotes smooth movement which is helpful in accurate positioning where the displayed characters are small or where accurate tracing of a pattern is required.[376]

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[372] Engelbart 1996
[373] Engelbart 1963
[374] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 96.
[375] Ibid, 98.
[376] Engelbart. X-Y Position Indicator for a Display System, claim 6.

Engelbart went on: “The position indicator control is held by the hand and moved over any surface, such as a desk top (or even may be moved by the feet).”[377] The transformation of the drawing tool in the computer system from a hand held device to possibly a feet held device reflects the engineering’s lack of appreciation of the hand in the drawing process.

In general, the mouse or bug referred to both the hand held device that the operator moves, and the cursor that moves on the screen.[378] Like a bug crawling on the surface of a window, Engelbart’s bug crawls on the computer’s window. In a recent publication describing Engelbart’s mouse invention, an article in the *New York Times* clarified that the computer mouse is actually different from the bug. The mouse is the hand held device whose name evokes the memory of “a small, furry creature given to scurrying across flat surfaces,” [379] and the bug “was the cursor on a computer screen, not the mouse. The cursor was also called the CAT.” Consequently, Engelbart’s “CAT” is the cursor on a computer screen that chases after the tailed desktop device that is known today as the “mouse”.[380] (See Figure 18)

[377] Ibid, claim 2.
[378] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 98.
[379] It is possible that the idea of a cat chasing after a mouse in the computer system was inspired by an American animated series of short films called *Tom and Jerry* that were produced between 1939 and 1957. These series centered on a rivalry between its two main characters, a cat called *Tom* and a mouse called *Jerry*. These series were popular around the time of the mouse invention and were voted in 1961 as the “top-money making short subject series of the year.” Christopher P. Lehman, *American Animated Cartoons of the Vietnam Era: A Study of Social Commentary in Films and Television Programs,1961-1973* (Jefferson, N.C.: McFarland & Co., 2006), 24.
[380] Markoff, "*Computer Visionary Who Invented the Mouse*."

Figure 18: Douglas Engelbart's CAT and Mouse. (Drawn by the author)

Sketchpad's Rubber Band Line

Sutherland's description of this new line drawing resembled a rubber band cut open, so that it became an elastic string with two ends. The Sketchpad line was made of three parts: two end points and a segment stretched from the initial point, determined by the system's light pen to a second location indicated by the movement and direction of the drafter's hand across the Sketchpad window. The Sketchpad line was not made of lead or ink; instead it was imagined to resemble the material property of a rubber band. As Sutherland stated: "If we point the light pen at the display system and press a button called 'draw,' the computer will construct a straight line segment which stretches like a rubber band from the initial to the present location of the pen."[381]

Sketchpad's light pen was used to create line segments and was described in Sutherland's dissertation as a "rubber band" that is stretched, by moving the pen, from an initial starting point with defined coordinates to another part of the screen, anchoring it as the end point.[382] Although Sutherland's "rubber banding" was also known as "inking-up,"[383] this new line invention was different from the ink line.[384] Sutherland described the process of drawing a line in Sketchpad as the following:

> To initially establish pen tracking, the Sketchpad user must inform the computer of an initial pen location. This came to be known as 'inking up,' and was done by 'touching' any existing line or spot on the display whereupon the tracking cross would appear. If no picture has yet been drawn, the letters INK are always displayed for this purpose. Sketchpad uses loss of tracking as a 'termination signal' to stop drawing. The user signals that he is finished drawing by flicking the pen too fast for the tracking program to follow.[385]

Later, with the development of the computer graphics that evolved from Sketchpad, the rubber band line became known as a vector.[386] Although Sutherland was familiar with the term vector and used it several times throughout his dissertation, he did not use the term to describe his new line invention.[387] Instead, Sutherland chose to use the term rubber band when describing his new line.[388] Yet researchers in the field of computer science usually give a narrower description of

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[381] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 18.
[382] Tom Sito, *Moving Innovation: A History of Computer Animation* (2013), 42.
[383] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 88.
[384] *Inking-up* is a term that comes from the use of ruling pens to draw final technical drawings, and had an important role in the quality of the "draftsmanship" in traditional drawing practices. It was believed that the draftsman's pen or pencil was a part of himself and an extension of his hand, and that the draftsman had to acquire an acute sense of the feel of his pen or pencil on the paper, "a delicacy of touch that is not unlike that of the skilled surgeon who is said to be able to almost see with his fingertips." Furthermore, the ruling pen had to be handled with delicacy to avoid cutting grooves on the surface of the paper, and had to be held with firmness to produce lines that are smooth, even and defined throughout the length of the line. Oliver Reagan "Notes on Drafting." In *Pencil Points Reader: Selected Readings from a Journal for the Drafting Room*, edited by George E. Hartman, Jan Cigliano (New York, Princeton Architectural Press, 2004), 6.
[385] Ivan E. Sutherland, "Sketchpad: A Man-Machine Graphical Communication System," in *Proceedings of the May 21-23, 1963, spring joint computer conference* (Detroit, Michigan: ACM, 1963), 334.
[386] A vector is defined as an entity having both magnitude (length) and direction. Banesh Hoffmann, *About Vectors* (Dover Publications, 1975), 1.
[387] Sutherland, "S*ketchpad: A Man-Machine Graphical Communication System*." 82, 83, 122, 144.
[388] Sutherland used the term rubber band twice to describe his new line invention twice in his dissertation. Ibid, 18.

Sketchpad, by focusing on the fact that "Sketchpad was a vector system."[389] Mainly because Sketchpad's CRT monitor gave the computer the ability "to turn on and off lights that appeared to make graphical patterns."[390] According to Dan Ryan, a professor of engineering graphics at Clemson University:

> Sutherland seemed to find the perfect solution for many of the graphics problems he faced. Even today, many standards of computer graphics interfaces got their start with this early Sketchpad program … These early computer graphics were Vector graphics, composed of thin lines whereas modern day graphics are Raster based using pixels.[391]

While the rubber band line and vector are similar, both having two ending points, length and direction, vectors were originally developed as hypothetical lines to aid mathematicians in the study of complex numbers,[392] whereas rubber band lines originated from the concept of using physical strings to construct a drawing. Ryan described the difference between vector graphics and raster graphics to his engineering students with a story about a shipwrecked sailor.[393] In his story, the sailor:

> Created an SOS sign in the sand by arranging rocks in the shape of the letters SOS. He also had some brightly colored rope, with which he made a second SOS sign by arranging the rope in the shapes of the letters. The rock SOS sign was similar to raster graphics. Every pixel has to be individually accounted for. The rope SOS sign was equivalent to vector graphics.[394]

In recent publications in the field of electrical engineering and computer science, the term *rubber-band sketch* was used to describe geometrical wiring in machine design and to express

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389 Susan Schreibman Ray Siemens, and John Unsworth, *A Companion to Digital Humanities* (Wiley, 2008), 527.
390 Kalay, *Architecture's New Media : Principles, Theories, and Methods of Computer-Aided Design*, 168.
391 Dan Ryan, *History of Computer Graphics: Dlr Associates Series* (AuthorHouse, 2011), 29.
392 Michael J. Crowe, *A History of Vector Analysis: The Evolution of the Idea of a Vectorial System* (Dover Pub., 1967), 6.
393 Raster graphics is a term that is used to describe how computers are used to display images by a dot matrix. Raster displays are composed of spots of light that are often referred to as pixels. Allen Kent and James G. Williams, *Encyclopedia of Microcomputers: Volume 14 - Productivity and Software Maintenance: A Managerial Perspective to Relative Addressing* (Taylor & Francis, 1994), 221.
394 Ryan, *History of Computer Graphics: Dlr Associates Series*, 29.

spatial design constraints such as wire width and wire spacing.[395] In the 1980's, Roland L. Rivest, a professor of electrical engineering and computer science at MIT, originally proposed considering wires as rubber bands.[396] The term *rubber-band sketch* was introduced in 1991 to describe Multichip Module (MCM) packaging aspects in computer designs, particularly, the topological routing of one layer that included flexible wires.[397] In the geometrical wiring of a Multichip Module packaging system:

> A sketch represents a topological routing of one layer. It consists of a set of rigid objects, called features, F, and a finite set of flexible interconnecting wires, W. A wire in W is a simple path between two points in F. Since routing topology can be represented through many different sketches a canonical form of sketches, called rubber-band sketches, is used. In rubber band routing, individual wires are treated as elastic rubber bands that contract to the shortest possible length that still maintains the same topology. A rubber band wire is a wire with minimum-length routing, which is a polygonal path whose vertices are the points in F. If all wires in W are rubber bands, W is a rubber-band sketch.[398]

With the new computer line drawing the symbiotic partnership was made possible with the elastic line that was stretched in the new drawing space. Sketchpad's rubber band line stretches from the initial points determined by the human user to its final position according to the computer program, thus the computer's hand cooperates with the human's hand in making the drawing. (See Figure 19)

[395] Naveed A. Sherwani, Qiong Yu, and Sandeep Badida, *Introduction to Multichip Modules* (Wiley, 1995), 232. Also, see Mysore Sriram and Sung-Mo Kang, *Physical Design for Multichip Modules* (Kluwer Academic Publishers, 1994), 117.
[396] Ernest S. Kuh, *Multichip Modules* (World Scientific, 1992), 85.
[397] Sriram Dasu and Charles Eastman, *Management of Design: Engineering and Management Perspectives* (Springer Netherlands, 2012), 159.
[398] Kuh, *Multichip Modules*, 85.

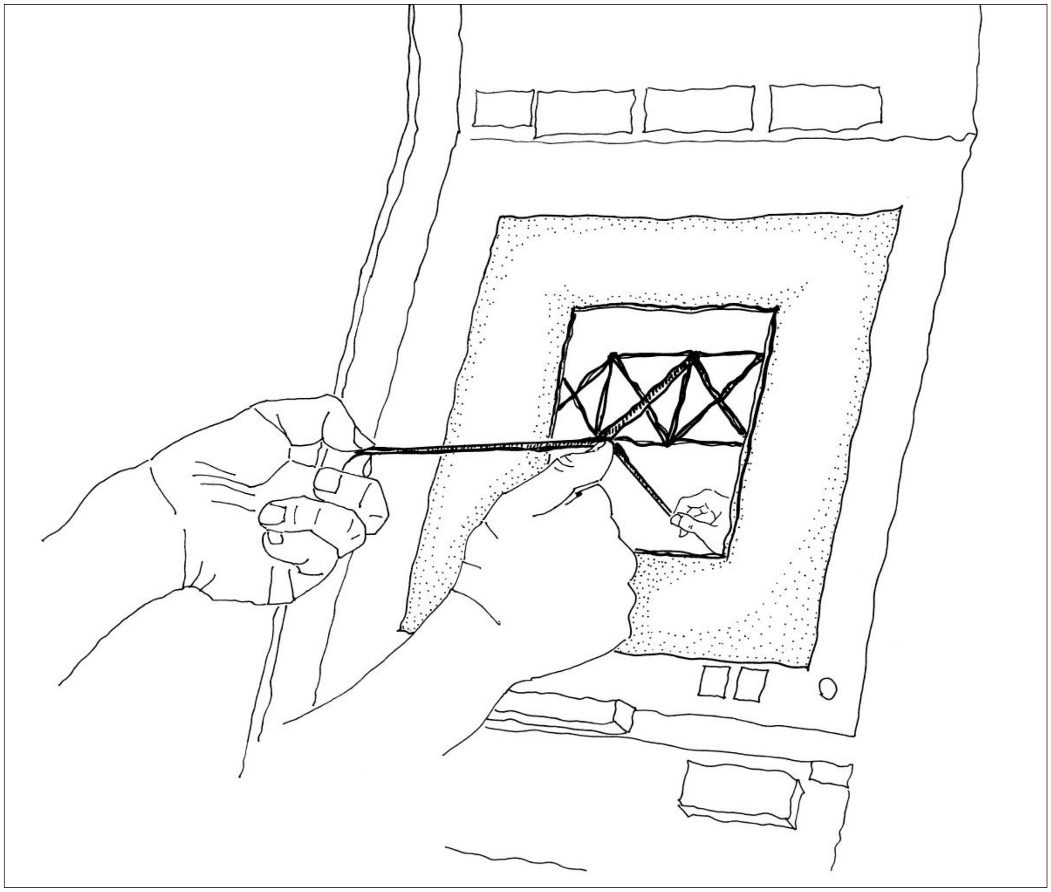

Figure 19: Using Sketchpad to create rubber band lines in the TX-2 computer. (Drawn by the author)

Snapping the Rubber Band Line

Although Sketchpad relied on a Cartesian coordinate drawing structure to define and store point locations in computer memory, there was no visible representation of a grid on the TX-2 computer window. Sutherland intended that the lines created in Sketchpad's coordinate system connect at the corners and snap at the edges, and described this feature in his Sketchpad dissertation in the following statement:

> When creating new points to serve as the start of line segments … an existing point is used if the pen is aimed at one when the new point would be generated. Thus, if one aims

> at the end of an existing line segment and presses ‘draw’ the new line segment will use the existing point rather than setting up another point which has the same coordinates.[399]

With the idea of rubber band lines, comes the idea of a snap.[400] Coons described the snapping feature in Sketchpad as an internal process that was executed by the computer and that was not necessarily achieved by the human operator with the light pen, as he stated:

> Sketchpad could attach one line to the end of another separated line by means of toggle switch instruction, even if the light pen would not attach the lines precisely on the screen. The computer interpreted the instruction in such a way that the two lines were attached with mathematical precision at the end point, so that they were truly concurrent.[401]

A program called the “Pen Space Location,” (PSL) was adopted for the three-dimensional sketching method for Sketchpad. This program performed two important functions: it was able to define a point in space called the Pen Space Location PSL by assigning a depth coordinate to the pen location, and it permitted precise positioning of the PSL and drawing of lines with “coarse” light pen motion.

The program was designed to compensate for any lack of skill by an approximate estimation of the intention of the drafter and therefore complete the task at hand. For example, if the drafter wanted to make a new line drawing that connected to a previous line, the drafter would simply have to move the light pen close to an imaginary field that exists around the previously drawn line. The PSL program was designed to assume that the drafter automatically wants to begin the new line drawing from a point on the existing line, and therefore set the initial point coordinate data to the closest point on the existing line in the computer storage system. As Johnson stated: “The Pen Space Location program also determines end points and intersections of lines in this manner. Thus a steady hand is not required to construct accurate drawings.”[402]

The role of the drafter in the drawing process was defining the end points of the line segment, thereby replacing the traditional drawing process from drawing as pulling along to drawing as pointing, leaving the pulling chore to the computer.

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[399] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System.*" 88.
[400] Carroll Lisby, *Presto! Laughter: More Than 2,800 New Laugh-Lines for Your Favorite Magic Tricks* (Xlibris Corporation, 2010), kindle edition.
[401] Coons. "*Computer-Aided Design*." 9.
[402] Johnson, " *Sketchpad III: A Computer Program for Drawing in Three Dimensions*." 351.

The relationship between drawing and pulling ropes can be traced back to the Renaissance, particularity to architect Leon Battista Alberti's architectural treatise titled *On the Art of Building in Ten Books* that was written about 1450.[403] According to the architectural theorist Marco Frascari:

> Alberti's understanding of denoting lines (lineamenta) derives from the use of tracing lines, ropes, ribbons, strings or threads made with flax fibers and used by the builder on construction sites during the facture of buildings. These denoting lines range from the lines pulled between different pickets and the battered boards to map out the footprint of the building, to the taut strings that, stretched at the end with weights, guide the masons in their erecting of stone and brick walls.[404]

Alberti believed that the art of building was divided into two aspects: "lineaments" and "matter." For Alberti, lineament was the "product of thought and required the mind and the power of reason," while the aspect of matter depended "upon preparation and selection."[405] Emmons believed that Alberti's particular use of the term lineaments emphasizes "design as first a geometrical line in the mind and only thereafter construction in material by the builder."[406] In both views, the concept of a line as a string is present.

Although Sketchpad's rubber band line and the traditional ink on paper line may appear outwardly similar, these two lines are internally different. The difference between them is that the traditional line that is drawn across a surface retains the character of its making and has other qualities in addition to a beginning and an end,[407] while Sketchpad's line segment is simply a straight connection between two endpoints determined with the light pen in the computer's Cartesian coordinate system.[408] Sketchpad's cathode ray tube was capable of drawing dots and

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403 Alberti, *On the Art of Building in Ten Books*.
404 Frascari, *Eleven Exercises in the Art of Architectural Drawing: Slow Food for the Architect's Imagination*, 99.
405 Alberti, *On the Art of Building in Ten Books,* Prologue 5.
406 *The Material Imagination: Reveries on Architecture and Matter*, 90.
407 Xtine Burrough. *Foundations of Digital Art and Design with the Adobe Creative Cloud* (Berkeley, California: New Riders, 2013), 4.
408 Emmons and Kassem, "*Architect-Computer Symbiosis*." 55.

lines according to the coordinates established by the operator.[409] Rather than compute an entire line, "only two dots could be used to establish its starting and ending points."[410]

With the invention of Sketchpad the relationship between the hand and body in the physical drawing process was discarded. Sketchpad's light pen "linked the hand and eye of the user with the display on the screen. We could say that the pen functioned as both an eye on a wand and a pen on the screen. As such, it reversed the trend in the history of input-output technology, from the telegraph to the typewriter, that led to an unlinking of what the hand does from what the eye sees."[411]

As in the light-pen schema, the transmission capacity of the mouse is determined in part by the resolution of the display with which it is used.[412] But unlike the light pen schema that is dependent on the dimensions of the computer screen, the transmission capacity of the mouse is independent of the dimensions of the desktop mouse pad.[413] Despite the fact that the human user had to develop skills to use the mouse, as opposed to the intuitive use of the light pen, the mouse was more appealing than the light pen. Licklider was unable to explain this phenomenon, he stated:

> [Engelbart's] mouse works with a hand offset from the target, from the work. Herb Jenkins at the Lincoln Laboratory back in the early 1950s did studies to determine how various data-take-off arrangements depended upon how much offset there was between the hand and the work and plotted function. The study showed it was bad, by a factor of two, to have an offset of eight or ten inches. And yet, that seems not to have affected the popularity of the mouse device. I know 20 people who use mice for every person who uses a light pen; I can't understand that, but it seems to be true.[414]

Engelbart described the notion that inspired the invention of the computer mouse, as improving man's intellect and thereby bringing about a way of life where the human feel for a situation could coexist with the use of technology and electronic aids. Engelbart stated:

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409 Michael F. Cohen and John R. Wallace. *Radiosity and Realistic Image Synthesis* (Boston: Academic Press Professional, 1993), 4.
410 Burrough, *Foundations of Digital Art and Design with the Adobe Creative Cloud*, 4.
411 Robert, *"Man-Machine Console Facilities for Computer-Aided Design*."88.
412 Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 99.
413 Ibid, 99.
414 Licklider. "*Some Reflections on Early History*." 119.

> I am not numerically oriented; my vision has always facilitated discursive thinking and collaboration … In fact, all our computer developments into the 1970s (synchronous distributed shared-screen conferencing, windowing systems and outlining tools, the mouse, among others) and since are secondary derivatives of this conceptual framework; I view the computer merely as a supportive tool.[415]

Kay described this aspect of Engelbart's thought in the following:

> One of the phrases that he [Engelbart] used that I particularly liked was 'thought vectors in concept space'. I'm not sure I understand what he meant, but what I think is that you are creating an extension of the kinds of spaces that you think in terms of inside of your head. So, you are creating an augmentation of the ways of thinking, the ways of representing, the ways of associating that was now going to be extended in a way somewhat analogous to the way writing has extended us but somewhat more like the way we actually think.[416]

Operating the hand held drawing device from a distance from the display meant that a form of on-screen tracker, known as cursor, was needed to establish correspondence between the "device space and the display space." While this may seem an obvious concept today, it was a newly developed concept that emerged from the new form of human-computer interaction in the 1960s.[417] In the documentation for the patent of the mouse, Engelbart stated that:

> While the position indicator control can be used merely to cause a change in cursor position, and other means such as a typewriter can be used for adding to the pattern, the indicator control can be used in other ways. For example, the position indicator control can be placed on a drawing to be displayed on the CRT, and then the indicator control can be moved to trace the lines of the drawing with the computer causing corresponding lines to be displayed on the CRT.[418]

Engelbart's mouse invention made the cursor that moves within the computer space independent from any intervention from the computer's screen.[419] As he stated: "When the user employs a

[415] C. Engelbart Douglas, "Toward Augmenting the Human Intellect and Boosting Our Collective Iq," *Commun. ACM* 38, No. 8 (1995), 30.
[416] Rosemary et al., "50 Years after: As We May Think". The Brown/Mit Vannevar Bush Symposium." 55.
[417] MacKenzie, *Human-Computer Interaction : An Empirical Research Perspective*, 8.
[418] Engelbart. X-Y Position Indicator for a Display System, claim 6.
[419] Bardini, *Bootstrapping: Douglas Engelbart, Coevolution, and the Origins of Personal Computing*, 98.

mouse and a chord keyset combination, he or she can alternatively input both text and graphics without looking at his or her hands, freeing the eyes to contemplate the results of these hand gestures turned into graphical symbols, in real time."[420] Additionally, according to Engelbart:

> A disadvantage to the light pencil and other similar devices is that they generally require the human operator to hold the pencil against the CRT with one hand while changes are made. Consequently, the operator does not have both hands free to enter changes, as by typing them in, and cannot move to equipment only a step away from the CRT. Furthermore, the light pencil often covers part of the area of the CRT display where changes are to be entered, which interferes with the process.[421]

From the use of the light pen either to select visible objects by dragging the light pen across the cathode ray tube, to the programmed operations of making line drawings, Engelbart's mouse eliminated the imposition of the hand and device between the eye and display. Hookway believed that Engelbart's x-y position indicator was a determent to the light pen because while the light pen required the imposition of the hand and device between the eye and display, the mouse would essentially clear the channel between eye and display. As a result, "an overall system of hand/device and eye/display would be moved toward a further integration."[422] It was believed that the "fragile" light pen that required the drafter to "pick up the device" was a hindrance to the experience of working with the computer's interface.[423] Engelbart's mouse was an "indirect" pointing device that eliminated hand fatigue and hands obscuring the screen, but required the hand to locate the device and therefore relied on more "cognitive processing and hand/eye coordination" to move the onscreen cursor to the desired location.[424]

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[420] Ibid, 99.
[421] Engelbart. X-Y Position Indicator for a Display System, claim 1.
[422] Hookway, *Interface*, 151.
[423] Ben Shneiderman and Catherine Plaisant, *Designing the User Interface: Strategies for Effective Human-Computer Interaction* (Boston: Addison-Wesley, 2010), 315.
[424] Ibid, 315.

Chapter Seven: Sketchpad Expands Into the Third Dimension

Sutherland's two-dimensional drawing system was followed by a three-dimensional expansion called Sketchpad III that was developed by Roberts and Johnson. As Coons stated:

> The classic Sketchpad system was followed by *Sketchpad 3.* This name indicates an extension of the two-dimensional Sketchpad into three dimensions. Sketchpad 3 allows direct communication with the computer, which results in three-dimensional images. For instance, the operator can see a three-dimensional surface, and furthermore, have it rotate in space. In one sense, Sketchpad 3 is less sophisticated than Sutherland's original version, which was a new idea. But in another sense it is more sophisticated. After all, it is easy to draw two-dimensionally, but it is not so easy to teach the computer that there is a three-dimensional space and that the cathode ray tube is not the world or the universe, but that there is something beyond it.[425]

Roberts's program was part of his doctoral dissertation titled *Machine Perception of Three Dimensional Solids* that was submitted to MIT in May 1963, four months after Sutherland's PhD thesis defense. On the day he defended his PhD dissertation, he used the same TX-2 computer for demonstrations before a PhD committee that included many faculty members who had been on Sutherland's committee.[426]

Sutherland and Roberts cooperated in developing the overall Sketchpad system,[427] and each acknowledged the other's contributions in his dissertation. In Sutherland's dissertation, he thanked him publicly: "I wish to thank Lawrence G. Roberts, who was a constant source of answers to specific questions I had both about the best ways to program TX-2."[428]

Also, as Sutherland went on: "Roberts reports a computer program able to recognize simple objects in photographs well enough to produce three dimensional line drawings for them. Roberts [program] will be compatible with the three dimensional version of Sketchpad."[429] The

[425] Coons. "Computer Aided Design." 11.
[426] Norman, *From Gutenberg to the Internet: A Sourcebook on the History of Information Technology,* 41.
[427] Lawrence G. Roberts, "Machine Perception of Three-Dimensional Solids" (Massachusetts Instituted of Technology, 1963), 185.
[428] Sutherland, *"Sketchpad: A Man-Machine Graphical Communication System*." 11.
[429] Ibid, 114.

details of the actual perspective-generating algorithm that could be executed by the computer were published in Roberts's dissertation.[430]

Roberts' program made it possible for the Sketchpad user to create line drawings in the computer's three-dimensional coordinate drawing space. Using the light pen, the drafter was able to assign an address to all the endpoints necessary to create a representation of a solid object. Like the rubber band line segment in the two-dimensional Sketchpad program, the rubber band line segment in Sketchpad III connected endpoints in the direction of three axes, thereby adding depth to Sutherland's drawing invention.

Teaching Sketchpad to Draw Objects

Roberts described the role of photographs taken with monocular lenses in the development of his own computer program. The science of photogrammetry, developed early in the twentieth century, was used to elucidate true information from photographs, which is "to work perspective backwards."[431] Photogrammetry allows one to reconstruct the position, orientation, shape and size of objects from pictures.[432] With the aid of photogrammetry "One can work perspective backwards if one knows some of the dimensions of the object photographed, or the ratio of certain dimensions."[433]

Roberts used monocular pictures to derive the computer algorithms for his program that resulted in perspective-generating algorithms that were similar to traditional perspectival techniques. His objective was to enable the computer to construct and display a three-dimensional array of solid objects from a two-dimensional photograph. To do this, Roberts had to analyze and mechanize the rules and assumptions of depth perception.

It was assumed that a photograph was a perspective projection of a set of objects that can be derived from familiar three-dimensional objects that are supported by a visible ground

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[430] Roberts, "*Machine Perception of Three-Dimensional Solids*."
[431] Booker, *A History of Engineering Drawing*, 28.
[432] Karl Kraus, *Photogrammetry: Geometry from Images and Laser Scans*, trans. Ian Harley and Stephen Kyle (Vienna: Walter de Gruyter, 2007), 1.
[433] Booker, *A History of Engineering Drawing*, 222.

plane.[434] In a perspective projection, the object is first translated and rotated so that the viewer, the screen, and the object are aligned, and the object is described in terms of an eye coordinate system having its origin at the fixed monocular eye of the viewer. The three coordinates are connected to each other both through the ratio of the distances between the viewer and the screen, and the screen dimension. Thus, an orthographic projection can be said to correspond to a perspective with the viewpoint at infinity, whereas in a perspective projection the distance of the viewer to the screen affects the ratio of the perspective composition. In effect, this ratio controls the amount of foreshortening that is represented on the screen. If the ratio is high, the screen image will appear foreshortened as if obtained with a telephoto lens, but if the ratio is low, a wide-angle view will be created.[435]

Roberts believed that with the aid of the computer he would be able to obtain a reasonable three-dimensional description from the edge information in a photograph through topological mathematical processes. He hoped that his dissertation would be a step further toward developments in the field of computer-aided three-dimensional systems.[436]

Roberts described the monocular photograph as a combination of a window with a camera or comparable device able to project the perspectival transformations onto this window, a homogenous plane; therefore, the points in the real world are transformed into points on the photograph. As with Renaissance perspective machines, the photograph is viewed from a fixed monocular point; in Roberts's system the perspective transformation varies depending on the camera used, the enlargement printing process and the coordinate system the real world is referred to.[437] However, Roberts proposed using a camera with long telephoto lenses to take a picture in an orthogonal projection, so that he would be able to compute the proper transformation without any consideration for the camera characteristics.[438] This was a challenging process, and some of the perspective transformations were not easily obtainable from the picture, or accurate enough for the computer; therefore, parts of these perspective transformations were derived mathematically.[439] Mathematical formulas, such as the *Perspective*

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[434] Roberts, "*Machine Perception of Three-Dimensional Solids*."159.
[435] Mitchell, *Computer-Aided Architectural Design*.
[436] Roberts, "Machine Perception of Three-Dimensional Solids." 159.
[437] Ibid, 162.
[438] Ibid, 166.
[439]Ibid, 167.

Theorem, allow one to construct perspective drawings “using nothing but mathematics.”[440] In Roberts’s dissertation, he described the “transformation of real world” as follows:

> The first assumption is that the picture is a view of the real world recorded by a camera or a comparable device and therefore that the image is a perspective transformation of a three-dimensional field. This transformation is a projection of each point in the viewing space, towards a focal point, onto a plane. The transformation will be represented with a homogenous, 4 X 4 transformation matrix P such that the points in the real world are transformed into points on the photograph.[441]

Renaissance perspective representation can be described as the “reproduction of an instantaneous view” where everything in the composition takes place at the same time, and is also perceived from one point of view. However, this representation is not an imitation of the visual perception, but rather an imitation of the visual impression of the original situation.[442] The reproduction of such representations relied on the development of a drawing system with established rules that were applied for making drawings of existing scenes and imaginary sceneries as well.[443]

Roberts concluded that some of the assumptions that the observer made were about the nature of the real world and some involved the observer’s familiarity with the objects. As a result, without these assumptions the picture would be just a flat two-dimensional image. With these two assumptions, the observer would rarely be confused about the depth of relationships represented in the picture. Roberts assumed that since humans agree closely on their depth impressions, it is acceptable to assume that their major assumptions are similar as well.[444]

Roberts was interested in analyzing pictures taken with cameras with long telephoto lenses because these lenses can take a picture that is close to an orthogonal projection, and therefore can be used to compute the proper transformation.[445] He concluded that the picture was a perspective view of the real world, that the objects represented in the picture could be described by transformations of known models, and that the objects represented in the picture were supported by other objects or by a ground plane. In his own work, Roberts restricted the

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[440] Marc Frantz and Annalisa Crannell, *Viewpoints: Mathematical Perspective and Fractal Geometry in Art* (PA: Princeton University Press, 2011), 13.
[441] Roberts. "*Machine Perception of Three-Dimensional Solids*."162.
[442] Kirsti Andersen, *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge* (New York: Springer, 2007), 3.
[443] Ibid, 3.
[444] Roberts, "*Machine Perception of Three-Dimensional Solids.*"
[445] Ibid, 166.

transformations to rotation, translation, and size changes. Then, from a picture, he extracted line drawings that he could represent in a three-dimensional space. These line drawings supplied Roberts with the input of graphic data, entered by inputting coordinates that described their locations.

Alberti also described this process of vision in terms of lines that he called *visual rays* that stretch between a fixed monocular eye and the object seen, resulting in a triangular pyramid formed by rays that converge from the eye as vertex.[446] Alberti was inspired by classical geometrical optics in his description and from optics he learned the idea that any point in front of the eye is perceived through the straight line, called the visual ray that connects the point and the eye. He also learned from optics the concept of the visual pyramid that consisted of all the visual rays connecting a given polygon and a given eye point so that the pyramid has the polygon as its base and the eye point as its apex.[447] Working with this knowledge from optics, Alberti conceived the idea of defining the image as seen from a given eye point of a given polygon upon a given picture plane that is situated between the eye and the polygon.[448] Alberti stated:

> I believe nothing more convenient can be found than the veil, which among my friends I call the intersection, and whose usage I was the first to discover. It is like this: a veil loosely woven of fine thread, dyed whatever color you please, divided up by thicker threads into as many parallel square sections as you like, and stretched on a frame. I set this up between the eye and the object to be represented, so that the visual pyramid passes through the loose weave of the veil. This intersection of the veil has many advantages, first of all because it always represents the same surfaces unchanged, for once you have fixed the position of the outlines, you can immediately find the apex of the pyramid you started with, which is extremely difficult to do without the intersection.[449]

The painter's panel represents a window through which the painter views the scene. The painting is the intersection of the window with the visual pyramid.[450] The window, which is made of a sheer veil, suggests a visual system that aids in the representation of a true image because of its transparency, transmitted light, and unmediated image.[451]

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[446] Friedberg, *The Virtual Window: From Alberti to Microsoft*, 28.
[447] Andersen, *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge*, 19.
[448] Ibid, 19.
[449] Alberti, *On Painting*, 65.
[450] David C. Lindberg. *Theories of Vision from Al-Kindi to Kepler* (Chicago: University of Chicago Press, 1976), 150.
[451] Friedberg, *The Virtual Window: From Alberti to Microsoft*, 15.

Sketchpad III and Alberti's perspective device offered the viewer a virtual image experienced from a fixed point. In Sketchpad III, data about the picture was processed and transformed from its original format into the type of structured representation needed to write the computer program.[452] To process the data from the picture, Roberts identified the intersection of the visual rays on the monocular picture by finding and scanning the points of intersection into the computer. To complete this task, he used an optical scanner called a facsimile scanner. This scanner was connected to the TX-2 computer at MIT's Lincoln laboratory, and was used to scan lines from the picture. By analyzing the camera transformations, Roberts was able to come up with the algorithms that mimicked these transformations in the computer program he wrote for his dissertation.

Roberts's efforts resulted in a computer program that could process a photograph into a line drawing, transform a line drawing into a three-dimensional representation and, finally, display the three-dimensional structure with all the hidden lines removed from any point of view.

In his dissertation, Johnson described and graphically illustrated the perspectival representation on the Sketchpad III window (See Figure 20), and explained that:

> The graphical interpretation of the perspective transformation indicated [he referred to a drawing that illustrated the intersection of the cone of vision with the drawing plane] represents the viewing surface of the CRT, but could just as easily represent the film in a camera, since the same model demonstrates the operation of a camera lens system.[453]

[452] Mitchell, *Computer-Aided Architectural Design*, 323.
[453] Johnson, "*Sketchpad 3 - Three Dimensional Graphical Communication with a Digital Computer*." 27

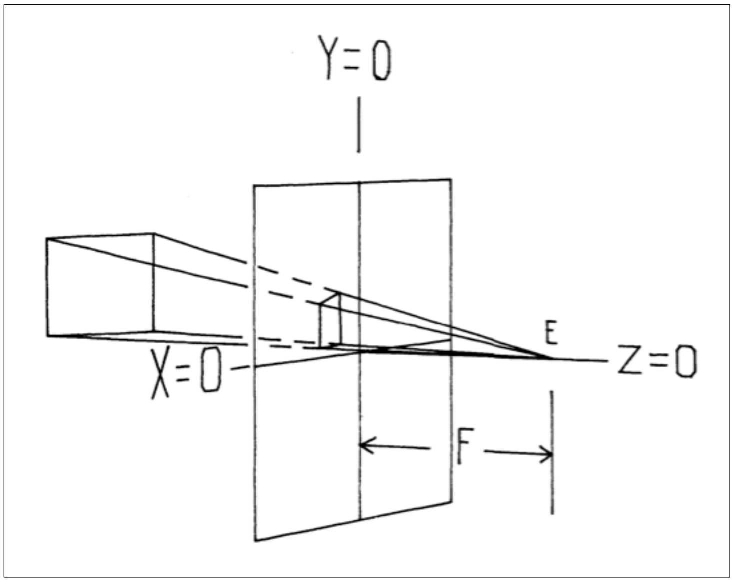

Figure 20: Graphical Interpretation of a Perspective Transformation, Timothy Johnson, "Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer" (Massachusetts Institute of Technology, 1963), 27. (By courtesy of MIT)

Roberts's perspective model, like Alberti's perspective model, simplified by reducing vision to a function that takes place at one stationary point, when in fact seeing involves two eyes that are movable. Many of Alberti's successors commented upon this problem, but never to the extent that it eliminated Alberti's perspective model. For instance, the German art historian Erwin Panofsky criticized the over simplification of vision in Alberti's perspective model in his treatise entitled *Perspective as Symbolic Form,* published in 1924, where he stated:

> Perspective transforms psychological space into mathematical space. It negates the differences between front and back, between right and left, between bodies and intervening space (empty space), so that the sum of all the parts of space and all its contents are absorbed into a single quantum continuum. It forgets that we see not with a single fixed eye but with two constantly moving eyes, resulting in spheroidal field of vision. It takes no account of the enormous difference between the psychologically conditioned visual image through which the visible world is brought to our consciousness, and the mechanically conditioned retinal image that paints itself upon our physical eye.[454]

Panofsky believed that central perspective representations did not present correct renditions of reality. Rather, they were a bold abstraction from reality, and by reality he meant the "actual subjective optical impression" of the viewer.[455] Panofsky stated that the two bold abstractions from reality lie in the two assumptions made about central perspective, which are "that we see with a single and immobile eye, and second, that the planar cross section of the visual pyramid can pass for an adequate reproduction of our optical image."[456] Here perspectival space is made possible by reducing the objects in its domain into defined points, which can be positioned in a homogenous geometric space that does not reflect the visual space and tactile space of reality.[457]

Nonetheless, Alberti's perspective technique continued to be the chosen system for perspectival representation in current practices.[458] Alberti's approach to perspective construction was appealing because it was an acquired skill that could be obtained by learning a geometrical procedure.[459]

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[454] Erwin Panofsky, *Perspective as Symbolic Form* (New York; Cambridge, Mass) Zone Books. Distributed by the MIT Press, 1991), 31.
[455] Ibid, 29.
[456] Ibid.
[457] Ibid, 30.
[458] Andersen, *The Geometry of an Art : The History of the Mathematical Theory of Perspective from Alberti to Monge*, 19.
[459] Ibid, 22.

Sketchpad III and Gibsonian Perception

Roberts relied heavily on the psychologist James J. Gibson's cues of depth perception in writing the algorithms necessary to enable the computer to perceive three-dimensional solids. Roberts stated:

> There has been a large volume of psychophysical research on human depth perception and shape recognition. From all this I have tried to isolate the ideas and theories which are used to explain our monocular perception of a three-dimensional world. It will be apparent, however, that the work of Gibson is dominant in my mind, since his book is both clear and complete.[460]

In his dissertation, Roberts referred to J. J. Gibson's book titled *The Perception of the Visual World,* published in 1950. From Gibson's book, Roberts concluded that an effective representation of depth must mimic our experiences of the visual world of objects and surfaces and not the abstract projected forms and contours of the visual field on the retina.[461]

It is interesting to note that Gibson explained in his book that a renewed interest in optics at the beginning of the Second World War emerged due to developments in aviation. There suddenly became a need to understand the mechanism of binocular and monocular vision in order to train pilots in the Air Force,[462] and psychologists conducting experiments in this area concluded that the correct way to understand depth perception was through experiments conducted outdoors in the natural environment where the object perceived is supported by a continuous background surface.[463] It was this new approach to understanding depth perception as it relates to the horizon, called "ground theory," which was the organizing scheme of Gibson's book.[464]

Roberts was also interested in the visual perception that the observer experienced in the world, in a more complex environment, rather than simply seeing stimuli in a laboratory. For

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460 Roberts, "*Machine Perception of Three-Dimensional Solids.*" 161.
461 Ibid.
462 James J. Gibson, *The Perception of the Visual World* (Boston: Houghton Mifflin, 1950), 6.
463 Ibid.
464 Ibid, 7.

example, according to Roberts, one of Gibson's key depth cues was that of texture gradient. This was the effect of perspective on the grain of large surfaces; as the surface recedes, the grain becomes finer. Although texture gradient was described under the heading of depth cues in Gibson's book, Gibson considered the information provided by texture gradients to be more important than the information provided by depth cues, because texture gradients provided exact geometrical correlates of physical distance, whereas depth cues only gave an approximation. An example of such texture gradients can be understood from the spacing on the gradient in geometrically defined tiles; the more the distance of the observer from the tiles increases, the more the spacing between the tiles decreases.[465]

Other cues that Gibson described in his book, and that Roberts benefitted from, were the illumination variation that puts curved surfaces in relief, as well as the effect of blur with depth that one experiences when looking at objects in outdoor scenes. Roberts also benefitted from Gibson's chapters on Gestalt point of view on recognition of forms, shapes, and objects, where shadowy forms and plane geometry figures are the forms to be recognized.[466]

According to Roberts: "The continual perception of a cube, even when transformed, is consistent with Gibson's idea that shape perception is and must be invariant under perspective transformation. My idea of models also follows from this, since each model represents an invariant percept, and can be identified with any projection of itself."[467] Gibson defined invariant as the non-change that is constant during change; as he stated: "A series of transformations can be endlessly and gradually applied to a pattern without affecting its invariant properties. The retinal image of a moving observer would be an example of this principle."[468] Gibson was mainly concerned throughout his book with the role of the active observer.[469]

Gibson's ideas were developed further in a sequel to *The Perception of the Visual World* titled *The Ecological Approach to Visual Perception*. However, in the second book he went beyond the processing of sensory input in perception to the extracting of invariants from the experiences of the active observer and the perception of affordances in the environment. Affordances go beyond the perception of the visual characteristics of an object to perception of

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[465] E. Bruce Goldstein, "The Ecology of J. J. Gibson's Perception," *Leonardo* 14, no. 3 (1981), 191.
[466] Roberts, "*Machine Perception of Three-Dimensional Solids*." 161.
[467] Ibid, 162.
[468] Ibid, 153.
[469] Goldstein, "*The Ecology of J. J. Gibson's Perception.*" 192.

what the object affords the perceiver.[470] Gibson's approach to space perception provided a framework to help researchers think about perception.[471] And Roberts was one of those researchers.

Roberts employed Gibson's investigations on background surfaces and perception of the environment to extract information about objects from pictures taken with monocular lenses.[472] His objective was to write a program that could create a perspectival representation of an object and then generate a multitude of views of the same object but from different angles while maintaining lines of the object that recede and vanish in the horizon. Although Gibson in his book *The Perception of the Visual World* stated that scientists and psychologists concluded from several failed experiments in the area of visual perception that it was necessary to investigate this phenomena in the environment, and not in a controlled laboratory, because of the absence of earth's horizon, a necessary factor for true perception of the physical world,[473] Roberts did not adopt this view in his program. Consequently, in the Sketchpad III drawing there was no horizon line represented on the Sketchpad window. As a result, the objects that were represented appeared to be floating on the screen, weightless. (See Figure 21)

As a viewer looks at an object drawn on the Sketchpad window, he is meant to complete the image in his mind by associating the represented image with familiar objects. Even with the absence of a horizon line, the objects that were represented on the Sketchpad window were meant to give the illusion of lines that converged to a vanishing point. In Gibson's book *The Perception of the Visual World* he stated that Gestalt psychology had a role in the development of many of his ideas that he discussed in his book.[474]

Roberts benefitted from Gibson's chapters on Gestalt point of view on recognition of forms, shapes, and objects, where shadowy forms and plane geometry figures were the forms to be recognized.[475] According to Roberts: "The continual perception of a cube, even when transformed, is consistent with Gibson's idea that shape perception is and must be invariant under perspective transformation. My idea of models also follows from this, since each model

[470] Ibid, 193.
[471] Ibid, 195.
[472] Roberts, "*Machine Perception of Three-Dimensional Solids.*"
[473] Gibson, *The Perception of the Visual World*, 24.
[474] Ibid, 25.
[475] Roberts, "*Machine Perception of Three-Dimensional Solids*."161

represents an invariant percept, and can be identified with any projection of itself."[476] Gibson defined invariant as the non-change that is constant during change and depended on the role of the active observer.[477]

Perhaps it was Gestalt theory that inspired Roberts to eliminate the horizon line by assuming that the person looking at the Sketchpad window would be able to complete the image in his mind and mentally add a horizon line that is not represented on the screen. The lack of a horizon line that represents earth in a Sketchpad drawing has a limiting effect on the space perception because it reduces the objects represented to abstract geometric shapes and surfaces rather than making them resemble real objects. This method of representing objects as abstract geometries is based on Descartes study of the axes of empty space. Gibson believed that the Cartesian approach was ineffective in space perception and favored Euclid's observations on geometry because they were closely related to earth.[478] Furthermore, Gibson believed that the presence of the geometry of a horizontal plane that indicates flat earth was essential to make evident to the observer the affordances in the environment.[479]

The earliest drawings that were created with the Sketchpad III program were in wire frame mode because the programmers of Sketchpad were unable to create algorithms that would generate surfaces.[480] Therefore, Gibson's texture gradient as a depth cue could not have been incorporated in a Sketchpad drawing. The same is true for other depth cues that Roberts used to extract information from photographs, such as "illumination variation", which puts curved surfaces in relief."[481] Like texture gradient, this other cue was not demonstrated in the earliest Sketchpad drawing due to the challenges of computer programming.

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[476] Ibid, 162.
[477] Goldstein, "*The Ecology of J. J. Gibson's Perception*."192
[478] James J. Gibson, *The Ecological Approach to Visual Perception* (Boston: Houghton Mifflin, 1979), 132.
[479] Ibid.
[480] Johnson, "*Sketchpad III: A Computer Program for Drawing in Three Dimensions.*"348
[481] Roberts, "*Machine Perception of Three-Dimensional Solids*."161

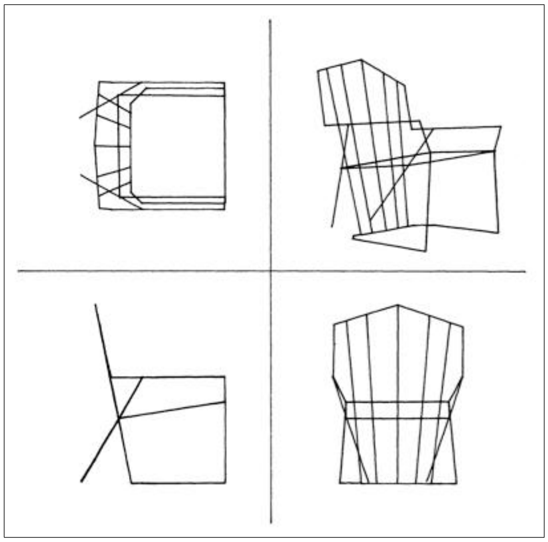

Figure 21: Wrought Iron Chair Design, Timothy Johnson, “Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer” (Massachusetts Institute of Technology, 1963), 37. (By courtesy of MIT)

Gibson’s book *The Perception of the Visual World* was published in 1950, and was available to Roberts. However, Gibson’s book *The Ecological Approach to Visual Perception* was published in 1979, sixteen years after the invention of Sketchpad and was not available to Roberts. Therefore, it was not possible for Roberts to know Gibson’s theory of affordance that would later be developed. However, Gibson’s theory of affordance resembles Heidegger’s understanding of things being ‘at hand.’ The word affordance is very familiar to human-computer interaction researchers and practitioners. The concept of affordance, adopted from Gibson, means “the possibility for action that we perceive in a situation.”[482]

[482] Alan, "*The Reification of Metaphor as a Design Tool.*" 491.

In the introduction to his book *The Ecological Approach to Visual Perception*, Gibson described the existing and previous writings on the subject of perception, including his own book *The Perception of the Visual World* as an over simplification of vision by assuming that we perceive the world with a fixed monocular eye as if it was detached from the body; whereas his the theory of affordance recognized that eye as an integral part of the moving body, experiencing the environment and identifying affordances.[483]

Roberts' program taught the computer to construct perspectival representations of solid objects inside the computer space and the perceiver experienced these representations by looking at them from the other side of the computer window. In 1965, Sutherland published a paper entitled *The Ultimate Display*,[484] in which "he described how one day the computer would provide a window into virtual worlds."[485] Sutherland viewed Sketchpad's display as the first step towards creating a virtual world using the computer, as he stated:

> The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.[486]

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[483] Gibson, *The Ecological Approach to Visual Perception*, 2.
[484] Ivan Sutherland, "*The Ultimate Display*" (paper presented at the Proceedings of IFIP Congress, 1965).
[485] Mario Gutierrez, Frederic Vexo, and Daniel Thalmann. *Stepping into Virtual Reality* (London: Springer Science & Business Media, 2008), 5.
[486] Sutherland, "*The Ultimate Display*."

Figure 22: Alice stepping out of Sketchpad's mathematical Wonderland. (Drawn by the author)

By placing Alice in Sketchpad's world, Sutherland created a connection between the drafter and Alice's bodily measurements. The first drawings created in Sketchpad lacked a measurable scale, and the observer had to depend on identifying familiar objects in the computer drawing to estimate an approximate scale, as one does when looking at a photograph or a television show. In fact, in Roberts's dissertation, scale was mentioned in relation to identifying sizes of objects from a photograph.[487]

Sutherland believed that it was: "impractical to assign any absolute scale factor to the page" because of the "magnification" feature of the display that allowed the user to zoom in on any part of the drawing, and because all information about the drawing was stored in the computer.[488] Sutherland combined the concept of the window with the concept of the telescope in his Sketchpad invention.[489] The display system in Sketchpad is referred to as *scope window*,

[487] *Roberts. "Machine Perception of ThreeDimensional Solids*." 167.
[488] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 71.
[489] The essential component in the telescope, microscope and CRT monitor is glass. The history of the development of the telescope is intertwined with the history of spectacles. Discovering spectacle lenses in the earliest telescopes

and the user is able to view on the scope any portion of the page desired and with any degree of magnification desired, similarly to viewing an object through a magnifying glass,[490] As he stated: "The magnification feature of the scope window-into-the page makes it possible to draw the fine details of a drawing."[491]

Emmons believed that scale was an essential component in an architectural drawing because it simultaneously provided a means for the hand to make drawings and for the mind to imagine a building.[492] In his paper titled *Size Matters: virtual scale and bodily imagination in architectural drawing,* Emmons gave examples of novels related to scale that were published during the seventeenth and eighteenth centuries, when the interest in scale became prominent with the development of the telescope and microscope.[493] The examples he gave were *Gulliver's Travels* by Jonathan Swift and *Micromegas* by Voltaire. Both novels explored the scalar characteristics of the telescope and the microscope, and described a person inhabiting an imaginary world of another size.[494] In both novels, a clear connection between scale and the fictional world was established by specifying numerical ratios and proportions between bodily scale and imagined worlds.

There is a parallel between Sutherland's Alice and the architect Claude Bragdon's Sinbad. Bragdon invented a tiny character called Sinbad, which he identified as himself in his book entitled *The Frozen Fountain*.[495] Like Sinbad, Alice is also reduced in size and represents the inventors' imagination moving through a drawing.

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that were invented made evidence of this connection. Glassmakers went through a series of lens developments to refine eyeglasses, but it was the invention of lens-grinding technology that was fundamental in the invention of the telescope. These improvements in the art of glassmaking suggest that the developers of these lenses were knowledgeable in optics. Rolf Willach, "The Long Route to the Invention of the Telescope," *Transactions of the American Philosophical Society* 98, no. 5 (2008), 3.

[490] The telescope and the microscope were inventions that have provided humanity with important scientific knowledge by extending human beings sight to observe things that were hidden from his unassisted eye. The definition of the telescope, however, goes beyond a simple physical description of an optical system whose resolution of distant objects is superior to the naked eye. The definition of the telescope also encompasses the theoretical description of the telescope as an instrument that revealed the unsuspected phenomena of the cosmos. Ibid, 1.

[491] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*."

[492] Paul Emmons, "Size Matters: Virtual Scale and Bodily Imagination in Architectural Drawing," *arq: Architectural Research Quarterly* 9, no. 3-4 (2005), 227.

[493] Ibid, 229.

[494] Ibid.

[495] Ibid, 223.

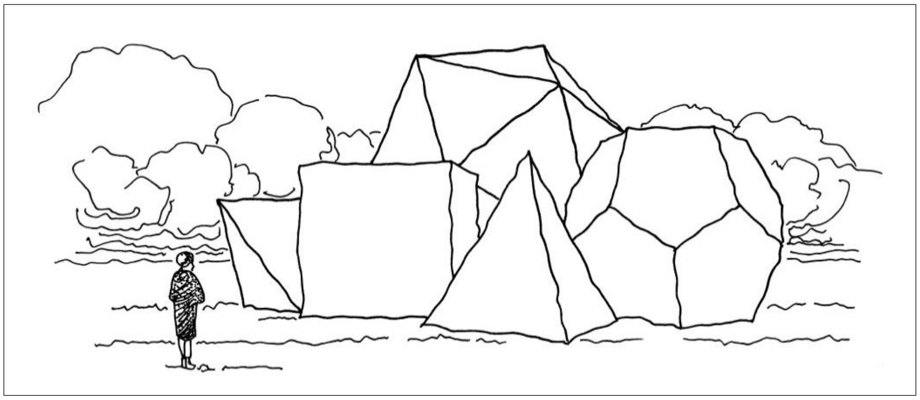

Figure 23: Drawing after Claude Fayette Bragdon's 'Sinbad, in the desert, discovers the five Platonic Solids.' (Drawn by the author)

Another example of a literary figure that explored the relationship between scale and the television around the time of Sketchpad was the British novelist Roald Dahl. In his novel *Charlie and the Chocolate Factory* published in 1964,[496] the chocolatier Mr. Willy Wonka gives a tour of his chocolate factory to a group of children. In one of the factory's rooms called the *television room*, Mr. Wonka explains his new invention called *television chocolate*, which will enable him to transport his chocolate bar to every house in the United States through the television. During a Willy Wonka commercial, a chocolate bar would appear on the television screen and the child watching the commercial could reach with his hand through the screen and take the television chocolate. However, in order to deliver the right size of chocolate bar to the child, the initial bar made at the factory had to be larger than the actual size of a regular chocolate bar, taking into account the shrinking effect that the television would have on the chocolate.[497] In this way, Dahl's novel reveals an awareness of the scalar manipulation of television on its representations.

In a televisual scene, the perceiver estimates an approximate size of the object displayed based on previous knowledge of the said object in reality. For example, regardless of the size of the television monitor and the represented size of an apple on the CRT screen, the perceiver knows that the actual size of the apple is similar to the size of an apple that fits in the palm of his hand.

[496] Roald Dahl, *Charlie and the Chocolate Factory* (New York: Knopf, 1964).
[497] Ibid, 124.

The same phenomenon occurs in a Sketchpad representation. The identification of the scale of the object represented on the Sketchpad screen depended on the perceiver's familiarity with the object based on previous experiences.

Unlike Gibson's concept of affordance, that is dependent on the perceiver identifying opportunities in his surrounding environment through his body, Sinbad and Alice are proxies that are placed into a fictional world created by the drafter. As a result, the imagined figure of Sinbad and Alice cannot perceive or identify affordances; rather, these figures are placed into the other world to enable the drafter to identify potential affordances that could be created in the imagined world.

In Gibson's concept of affordance, one is able to recognize what the surrounding environment affords – opportunities and limitations. For example, an animal walking in a forest on a flat surface that offers it support will abruptly stop at the edge of a steep hillside because it knows that the ground has ended and the hillside will not afford it more ground to walk on.[498] A man walking in the forest may see a fallen tree trunk and will immediately recognize that the fallen tree affords him a place to sit.[499] However in Sketchpad, the fictional character of Alice that Sutherland introduced as inhabiting the mathematical wonderland of the computer sits on a chair that is imagined to afford Alice a place to sit through a virtual representation that visually mimics the appearance of a chair and is created by the drafter on the Sketchpad window.

Affordance in Sketchpad is a mimicking of a small part of the greater affordances of the real world that Gibson described in his book. Perhaps "the composition and layout of surfaces" that Gibson described in relation to affordance inspired the inventors of Sketchpad to apply Cartesian thinking to Gibson's concepts. Moreover, Gibson in his book warned his reader not to link the concept of space to perception. He believed that: "Geometrical space is a pure abstraction. Outer space can be visualized but cannot be seen. The cues for depth refer only to paintings, nothing more. The visual third dimension is a misapplication of Descartes's notion of three axes for a coordinate system."[500]

[498] Gibson, *The Ecological Approach to Visual Perception*, 131.
[499] Ibid, 128.
[500] Ibid, 3.

The architectural historian Robin Evans believed that depth is invisible and that "only with the aid of touch could we infer the existence of the third dimension."[501]

In his book "*Ways of Worldmaking,"* the philosopher Nelson Goodman argued that there is no one real world, but that all worlds are real and are made up of "significant fragments and clues" that the artist makes skillful use of.[502] Goodman believed that there are multiple worlds that are constructed differently according to the criteria used by a given maker. For example, "the scientist is no less drastic, rejecting or purifying most of the entities and events of the world of ordinary things while … erecting elaborate structures on the basis of meager observations. Thus does he strive to build a world conforming to his chosen concepts and obeying his universal laws."[503] These fabricated worlds include the worlds of the sciences, the arts, and practice. These many versions conflicted with one another because a "whole truth" could never be managed and represented completely.[504]

In Sketchpad, Sutherland took significant fragments from the physical world such as gravity and culturally established gestures such as winking and supplemented these real fragments with invented elements that could create an alternative world to accommodate the drafter's fantasy. Furthermore, Nelson believed that growth in knowledge was achieved through an increase in acuity of insight and recognizing the familiar in the new creation.[505] In the process of world making in Sketchpad, as Nelson wrote and Sutherland demonstrated: "Discovering laws involves drafting them."[506]

In his writings on Sketchpad's potentialities, Sutherland described a room with a representation of a chair so real that one believes that one can sit on, a representation of a bullet that seems to be so real that one believes to be fatal, and yet everything represented in the room does not conform to the physical laws of the real world.[507]

Sutherland believed that Sketchpad opened a window to a fantasy world that began with fragments from the real world as a point of departure, but flexible in that it allowed the author of the other world to draft and change known laws, such as earth's gravity and friction, to create

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501 Robin Evans, *The Projective Cast : Architecture and Its Three Geometries* (Cambridge, MA: MIT Press, 2000), 351.
502 Nelson Goodman, *Ways of Worldmaking* (Indianapolis, Ind: Hackett, 1995), 14.
503 Ibid, 15.
504 Ibid, 20.
505 Ibid, 22.
506 Ibid, 22.
507 Sutherland, "*The Ultimate Display*."

new ones. For his efforts, Sutherland is commonly recognized as the "father of Virtual Reality systems."[508] Kay described the Sketchpad window as a virtual canvas that allowed the drafter to create innovative representations that did not conform to the physical laws of nature. Instead, it posited a new system that obeyed new laws that the drafter wanted to be held true.[509]

In 1968, to further immerse the observer in the virtual world of the computer, Sutherland built a head-mounted display that presented to the user left and right views of a computer generated scene.[510] According to Sutherland:

> The fundamental idea behind the three-dimensional display is to present the user with a perspective image which changes as he moves. The retinal image of the real objects which we see is, after all, only two-dimensional. Thus if we can place suitable two-dimensional images on the observer's retinas, we can create the illusion that he is seeing a three-dimensional object. Although stereo presentation is important to the three-dimensional illusion, it is less important than the change that takes place in the image when the observer moves his head. The image presented by the three-dimensional display must change in exactly the same way that the image of a real object would change for similar motions of the user's head… The desire to surround a user with information has forced us to solve the 'windowing' problem.[511]

Many computer scientists consider this device as "the first virtual reality system."[512] According to Licklider, Sutherland's invention consisted of a "helmet" that connected through a lever to the ceiling, and connected to a computer:

> And then the computer generated what you ought to see if you're looking in that direction. That was a marvelous display situation. The cathode ray tube was mounted on the same head rig so its output went directly into your eyes. You could move your head around and see different parts of the situation. It was nice for the computer because it didn't have to display what you weren't looking at. [513]

In his paper *The Ultimate Display*, published in 1965, [514] Sutherland discussed methods in which we perceive and interpret the world around us via the senses of the human body and our prior

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[508] Gutierrez, Vexo and Thalmann, *Stepping into Virtual Reality*, 5.
[509] newmediareader, "Earliest Known Footage of Ivan Sutherland's Mit Phd Dissertation Sketchpad," ed. Alan Kay (1962).
[510] Gutierrez, Vexo, and Thalmann, *Stepping into Virtual Reality*, 5.
[511] Ivan E. Sutherland. " A Head-Mounted, Three-Dimensional Display," (paper presented at the AFIPS Proceedings of the Fall Joint Computer Conference 1968), 757.
[512] Dan Saffer, *Designing for Interaction: Creating Innovative Applications and Devices* (Berkeley, CA; London: New Riders; Pearson Education, 2010), 12.
[513] Licklider."*Some Reflections on Early History*." 121.
[514] Sutherland, "*The Ultimate Display*."

knowledge of the world. Indeed: "Sutherland's research focused upon the embodied aspects of immersion in virtual reality. His research suggests that in order for a computer-generated environment to be effective it needs to engage as many senses as possible, rather concentrating solely on sight."[515]

Sutherland's two-dimensional version of Sketchpad aimed at creating an illusionary environment that allowed the drafter to make an imaginary world that would afford imaginary inhabitants such as Alice and Nefertiti impossible affordances and fictional places to inhabit. On the other hand, the three-dimensional extension of Sketchpad seems to have lost the feature of creating new environments for impossible affordances in favor of creating a realistic tool for work in the field of computer-aided manufacturing.

Though neither the two nor the three dimensional versions of Sketchpad anticipated the notion of affordance in the Gibsonian sense, the two-dimensional version of Sketchpad afforded the perceiver a fictional environment into which he could be swallowed, enabling him to create an alternative environment to the one he currently inhabited. In fact, the three-dimensional version of Sketchpad was also a step towards associating computers with manufacturing. This was achieved in the Sketchpad III system by dividing its window into four quadrants that could represent all the minute details of the object intended for manufacturing through a combination of three orthogonal views and one central perspective view. The goal eventually was to connect the Sketchpad III system to computer aided manufacturing hardware.[516]

The philosopher Alva Noë in his book called *Varieties of Presence*,[517] argued that: "Graphical user interface … is strikingly straightforward and easy to use … because it has been engineered precisely with our talents and inclinations in mind. It's been designed with no other purpose in mind than that of being easy for us."[518] What these considerations establish in the apparent ease of the use of the interface is in fact, "an illusion, itself an artifact of their engineering. We confuse excellence of engineering with naturalness and immediacy."[519] Therefore, the interface as a product of engineering should be used with an acute awareness of its limitations.

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[515] Melanie Chan, *Virtual Reality: Representations in Contemporary Media* (Bloomsbury Publishing, 2014), 15.
[516] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*."353
[517] Alva Noe, *Varieties of Presence* (Cambridge, Mass.: Harvard University Press, 2012), 103.
[518] Ibid, 103.
[519] Ibid, 104.

Chapter Eight: Sketchpad and the Game

As mentioned previously, Sketchpad's interface represented a new way of relating to technology. And like the Sketchpad interface that opened up a space for inhabitation, a game opens up a game space within which the event of the game happens.[520] Sutherland's playful attitude towards the computer can be inferred from his statement: "I, for one, am and will always remain a practicing technologist. When denied my minimum daily adult dose of technology, I get grouchy. I believe that technology is fun, especially when computers are involved, a sort of grand game or puzzle with ever so neat parts to fit together."[521]

Play is a voluntary activity that occurs outside ordinary life. It proceeds, within its own boundaries of time and space, according to established rules in an orderly fashion. Play begins and ends with itself.[522] Both the interface and the game come into being through a: "threshold condition; to be the user of an interface or the player of a game is to inhabit and engage that threshold, and to correspondingly be granted a kind of sacred status with respect to the interface or the game."[523]

Games and play possess a sacred aspect, and this is evident in the structural similarities between play and ritual.[524] The concept of games as defining a sacred space is common to two treatises in the theorization of games and play. The first is *Homo Ludens* by the cultural historian Johan Huizinga published in 1938,[525] and the second is *Man Play and Games* by the sociologist

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[520] A *game* is a system in which players engage in an artificial conflict, defined by rules that result in a quantifiable outcome. A game is something that one or more participants interact with in order to experience the play of the game. Although games occur within the real world, they maintain a boundary from real-life in both time and space. Games embody a contest of powers that can take many forms, such as cooperation or competition, from solo conflict with a game system to multiplayer social conflict. In a game, the player must follow rules. These rules provide the structure out of which play emerges, by specifying what the player can and cannot do. Finally, games have a quantifiable outcome. At the end of a game, the player has either won or lost or received a numerical score. Katie Salen, *Rules of Play : Game Design Fundamentals* (Cambridge, MA.: MIT Press, 2004), 80.

[521] Ivan Edward Sutherland. *Technology and Courage* (Mountain View, Calif.: Sun Microsystems Laboratories, 1996), 3.

[522] Robert Anchor, "History and Play: Johan Huizinga and His Critics," *History and Theory* 17, no. 1 (1978), 70.

[523] Hookway, *Interface*, 32.

[524] Ibid, 32.

[525] Johan Huizinga (1872-1945) was a Dutch historian best known for his theoretical work, *Homo Ludens: A Study of the Play Element in Culture*, published in 1938. In this work, Huizinga investigated the relevance of cultural history and the concept of play. Huizinga cited the influence of many philosophers including Heraclitus, Plato, Schiller and Kant. Anchor. "History and Play: Johan Huizinga and His Critics." 63.

and cultural theorist Roger Caillois, published in 1958.[526] Both theorists share the concept of the sacred as being separate from the ordinary life and treat the sacred as an entry into the space of the game. Huizinga stated that:

> All play moves and has its being within a playground marked off beforehand … Just as there is no formal difference between play and ritual, so the consecrated spot cannot be formally distinguished from the playground. The arena, the card table, the magic circle, the temple, the stage, the screen … are all in form and function playgrounds, i.e., forbidden spots, isolated… within which special rules obtain. All are temporary worlds within the ordinary world, dedicated to the performance of an act apart.[527]

The notion of the 'sacred in play' contains a contradiction, between freedom of action and confinement of play within the rules of a game space. Huizinga believed that the two characteristics of play are that it is both free and a stepping out of real life into a temporary space of activity with its own disposition.[528] Like Huizinga, Caillois also believed that play is free and separate from real life, and exists within the limits of space and time. However, what Caillois adds to Huizinga’s definition is that play is uncertain in its outcome and unproductive outside the boundaries of the game. The experience of playing a game is similar to the experience one has when entering a sacred space because both the game space and the sacred space are separate from the everyday life and both have their own unique set of rules that the person must follow while occupying the particular space.

According to the psychologist Jean Piaget,[529] for the child: “Play acquires rules or gradually adapts symbolic imagination to reality in the form of constructions which are still spontaneous but which imitate reality.”[530] Determining the nature of reality in the child was a challenging task for Piaget. One approach was to assume that the world for the child was made up of “external and internal worlds fused into one big form obeying some simple set of laws of

[526] Hookway, *Interface*, 32.
[527] Johan Huizinga, *Homo Ludens: A Study of the Play-Element in Culture* (Beacon Press, 1971), 10.
[528] Ibid, 8.
[529] Jean Piaget (1896-1980) was a Swiss psychologist who spent most of his career studying the psychological development of children. Dorothy G. Singer and Tracy A. Revenson, *A Piaget Primer: How a Child Thinks* (New York: International Universities Press, Inc., 1998), Preface xiv.
[530] Jean Piaget, *Play, Dreams and Imitation in Childhood* (London: Taylor & Francis, 2013), 87.

organization."[531] This aspect of child play may have influenced Sutherland's conception of Sketchpad through the Richter Blocks toy set he played with as a child.

Sketchpad and the Richter Blocks Toy Set

Like the game space, Sketchpad's interface operated according to a separation that helped to produce another state. In a game, the player accepts the limitations demanded by a set of rules in order to be part of the game play. Upon accepting the rules of the game, the player gains freedom of play within the bounded game space. For Huizinga and Caillois, sacred spaces within the world of games included card and board games, puzzles, children's games, make-believe, and theater.[532] In 2005, Sutherland revealed the source of his interest in computer graphics during a lecture entitled *Odysseys in Technology: Research and Fun,* presented at the Computer History Museum. In this lecture, Sutherland related that his interest in graphics began as a child playing with Richter blocks, as he said:

> Now people have sometimes asked why did I get interested in graphics? And I have to admit that I didn't read until I was in the third grade. I never did learn how to spell, but I did learn how to read drawings. I inherited from my mother's uncle a set of stone blocks that had been made by a German industrialist by the name Richter and sold as toys around the turn of the last century, around 1900s or so. And Richter invented a very important sales gimmick. If you had set four and you bought set four A, you then had set six, and if you bought six A, you then had set eight and so on. And Richter's cleverness in sales I think made him quite a lot of money but he did a bunch of other things as well in a little town near Dresden in what became Eastern German subsequently, in a little town called Rudolstadt [he then shows an image of the Richter blocks and explains with the image how these blocks are constructed] I played with these blocks building ever more complicated buildings as a kid and learned to read the cross sections as well as the projected view that you see here.[533]

The history of building blocks created for children's play is very long and the earliest hint that blocks may have existed as far back as the fourth century BC comes from a reference in Plato's *Laws*, paragraph 643, where Plato stated that: "The man who is to be good at anything must have

[531] *The Child's Conception of the World* (Maryland: Rowman & Littlefield, 2007), Preface xiii.
[532] Hookway, *Interface*, 33.
[533] Ivan E. Sutherland, *Odysseys in Technology: Research and Fun* (Mountain View, CA, US: Computer History Museum, 2005).

early training; the future builder must play at building … all the thoughts and pleasures of children should bear on their after-profession … and those who have the care of their education should provide them when young with mimic tools."[534] Another philosopher who believed in the importance of playing in an adult's life was Friedrich Schiller,[535] who argued that: "Man only plays when in full meaning of the word he is a man, and he is only completely a man when he plays."[536]

During the seventeenth century, stability in Europe prompted the growth of the German toy industry, achieved through the manual wood carving skills of the German peasantry. As a result, German toys began to spread to many other countries including England.[537] Growth of the toy industry resulted in a gradual change in attitude towards children and their education, and as a result, children were viewed as miniature grown-ups who were encouraged to develop their skills during childhood through constructive play. The German schoolteacher and architect Friedrich Froebel formulated a detailed theory of play involving building blocks. These building blocks were available for purchase as gifts and were arranged in sets that progressed logically in assemblage from simple to complex in terms of number, shape and size of the component blocks.[538]

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534 Plato, *Plato's Complete Philosophy Dialogues Anthologies.* Translated by Benjamin Jowett (Pandaowa Publishing, 2013), 101.

535 Friedrich Schiller (1759-1805) was a German philosopher, historian, poet and playwrights. Hans Pollak on Friedrich Schiller, (1759-1805.) In: "The Australian Quarterly 31", 4, (1959), 75.

536 Friedrich Schiller, *Letters Upon the Aesthetic Education of Man* (Kessinger Publishing, 1990), 50.

537 Pat Bruce Tina Froebel Blockplay Research Group Gura, *Exploring Learning : Young Children and Blockplay* (London: P. Chapman Pub., 1992), 2.

538 Ibid, 5.

Figure 24: Richter's Anchor Blocks. (Drawn by the author)

Froebel’s gift sets included a table that was meant to encourage the orderly arrangement of the blocks in precise relation and symmetry. Frobel believed that his building block set was capable of representing three forms: forms of life through which a child creates objects seen in the world, forms of beauty that are those where pattern and symmetry are prevailing, and forms of knowledge where abstract mathematical statements inform physical form.[539] Frobel’s gift sets continued to develop through the efforts of others who were influenced by Frobel but made changes to the toy blocks based on other criteria. And in the 1870s, these blocks were modified into sets of stone blocks with door and window details stamped on or specifically shaped, resulting in the Richter sets that was first patented in 1880, known as “Anchor Blocks.” The Richter Anchor Block sets contained detailed construction plans and grids that could be used to make abstract as well as representational constructions.[540]

[539] Ibid, 5.
[540] Ibid, 10.

Within the enclosure of the Richter Block's game space, any possible action is already confined to the rules of the game and is a condition that emerges out of the game actions themselves in their performance. As the game unfolds in actual play, it is defined moment by moment as an accumulation of actions. As a result, the game is not present in the sum of the rules but rather in the performance of the rules. In this way, play is a separation from life and is free within the confinement of a system of rules. For example, in the game of chess the rules are simple and limited in comparison to the practically infinite possible elaborations in play.[541] Sutherland believed that "the hard parts of programming are generally hard because it's understanding what the problem is that's hard."[542]

In a sense, Sutherland's approach to problem solving in the development of Sketchpad is similar to the challenges of the Richter blocks assemblage. In fact, Sutherland viewed his experiences working with the computer as a game that is similar to fitting pieces of a puzzle together. In his paper entitled *Technology and Courage,* published in 1996, Sutherland stated: "Technology is fun, especially when computers are involved, a sort of grand game or puzzle with ever so neat parts to fit together… If the technology you do isn't fun for you, you may wish to seek other employment. Without the fun, none of us would go on."[543]

This playful joy in Sutherland's Sketchpad can also be found in architecture. In 1876, the same architectural sets of blocks that inspired Sutherland attracted the attention of Frank Lloyd Wright's mother who was determined before her son's birth that he would become an architect. Wright acknowledged in his Autobiography that the Froebel blocks his mother gave him had a substantial impact on him.[544] Other early 20th century architects developed architectural toy blocks such as Bruno Taut and Hermann Finsterlin.[545] In 1919, Taut initiated a project that was known as the *Crystal Chain.* This project lasted for one year and included German architects like Finsterlin and Walter Gropius. The project resulted in the architectural toy design of Finsterlin's colorful wood blocks, which reflected Finsterlin's view of architecture as a living organism assembled from basic shapes and emotional impulses. And Taut's *Fairy Palace,* a set of colored

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541 Hookway, *Interface*, 34.
542 Frenkel. "An Interview with Ivan Sutherland." 714.
543 Sutherland, *Technology and Courage*, 3.
544 The ground plans of two of Wright's buildings, the Imperial Palace Hotel in Tokyo and Midway Gardens in Chicago were constructed using Froebel's blocks, thereby giving visual evidence of the blocks practical effect on Wright's work. Gura, *Exploring Learning: Young Children and Blockplay*, 10.
545 Juliet Kinchin and Aidan O'Connor, *Century of the Child: Growing by Design, 1900-2000* (Museum of Modern Art, 2012), 60.

glass building blocks, were manufactured by the *Luxfer Prismen Gesellschaft* in Berlin - the same company that sponsored the construction of Taut's Glass House.[546]

The presence of architectural play in sets of game tiles can also be found in architect Le Corbusier's design of Maison Domino.[547] In 1914, Charles-Edouard Jeanneret, known by his pseudonym Le Corbusier, conceived of the Maison Dominion as an open floor plan structure design to provide housing for victims of the First World War.[548] There is controversy regarding Le Corbusier's use of the name Maison Domino when his design was first published in the Purist journal *L'Esprit Nouveau* in 1921.[549] In recent publications on this topic, "the game was identified as the name's primary inspiration,"[550] possibly because the Domino game was a popular Parisian café activity during the time Le Corbusier conceived of his architectural design. Domino pieces are sometimes called tiles and are rectangular shaped game pieces that are typically twice as long as they are wide.[551] The design of Maison Domino resembled the Domino game both in the appearance of the domino tiles and the way in which the tiles were arranged in a game.[552]

Sutherland's architectural toy blocks made it possible to build and toy with models of architectural archetypes that included the floor, the wall, and the roof.[553] The original Greek meaning of the term *archetypes* is 'first form' and exists as a basis for all subsequent variations and combinations.[554] According to Coons:

> [Sketchpad] embodied several very important ideas. One was the principle of *archetypes.* If one were to draw a rectangle, using straight lines, then it would be never again necessary to construct a rectangle, because the simple rectangle, once drawn, becomes the generic archetype of the nature of the rectangle for future use. Likewise, if one designed a *thing* (such as a rivet), and that *thing* was important enough to be used again

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[546] Ibid, 61.
[547] Paul Emmons, John Hendrix, and Jane Lomholt, *The Cultural Role of Architecture: Contemporary and Historical Perspectives* (Milton Park, Abingdon, Oxon; New York, NY: Routledge, 2012), 132.
[548] Ibid, 132.
[549] Ibid, 133.
[550] Ibid, 134.
[551] Jennifer A. Kelley, *Great Book of Domino Games* (New York: Sterling Publishing Company, 1999), 9.
[552] Emmons, Hendrix, and Lomholt, *The Cultural Role of Architecture: Contemporary and Historical Perspectives*, 135.
[553] Architectural archetypes go beyond the elements mentioned above and encompass human experiences of the world. *Archetype* is a term that is applied to other fields of knowledge such as psychology. Vincent J. Scully and Neil Levine. *Modern Architecture and Other Essays* (Princeton University Press, 2003).
[554] Thomas Thiis-Evensen, *Archetypes in Architecture* (Oxford University Press, 1989), 17.

> and again, it would become, in that sense, an archetype and one would never have to design it again. It then would exist in the computer and could be replicated at any time.[555]

The Sketchpad user had the freedom to create customized archetypes based on personal interest. The psychiatrist Carl Jung believed that there was a link between the language of the archetypes and a fairytale.[556] In the fairytale, a person can express imaginary situations that may not happen in "real life" using invented archetypes. According to Jung: "Since the archetype is an autonomous content of the unconscious, the fairytale, which usually concretizes the archetypes, can cause the old man to appear in a dream [Jung is referring to a character in a story to explain his concept]."[557]

Sketchpad's Mathematical Wonderland

As stated previously, Sutherland used two popular twentieth century fictional characters to describe Sketchpad's potential representations. These characters are *Winking Nefertiti* and *Alice in Wonderland*. The reasons behind selecting these particular characters have been questioned by several researchers in the field of computer science, but few conclusions have been drawn as to the correct reason, mainly because Sutherland himself never really explained his motives and would generally answer that he simply wanted to make nice drawings.

Perhaps the character choice was a strategy on Sutherland's part to arouse the emotions of the potential users of Sketchpad, including "artists and draftsmen," by capturing the attention of these new audiences more effectively through the use of such popular figures. Sutherland described his first drawings that were created on Sketchpad's window as an amusement. Through Sketchpad's "cartooning" capabilities, "the computer display has amused many visitors."[558] Sutherland's use of Nefertiti and Alice to describe Sketchpad's representations reflected his

[555] Coons. "Computer-Aided Design." 10.
[556] Ursula Le Guin. "The Child and the Shadow." *The Quarterly Journal of the Library of Congress* 32, no. 2 (1975), 144.
[557] Carl G. Jung. *The Archetypes and the Collective Unconscious*, trans. R.F.C. Hull (Princeton University Press, 1981), 222.
[558] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 107.

delight in his graphical hardware by associating its representation with Nefertiti's beauty and Alice's youth and dreams.

In his dissertation, Sutherland described Sketchpad's potential applications that went beyond engineering drawings to his vision of giving life to his drawings through Sketchpad's ability to put motion to the computer drawings. Such applications included the girl Nefertiti winking, making Nefertiti's hair swing, changing the facial expression of a "sweet looking miss" to a smiling face, and giving motion to a "stick figure [that] could be made to pedal a bicycle."[559] (See Figure 25)

Figure 25: Sweet Smiling Miss, Ivan Sutherland, "Sketchpad: A Man-Machine Graphical Communication System." (Massachusetts Institute of Technology), 112. (By courtesy of MIT)

Sketchpad's cathode ray tube monitor strengthened the desire to render a constructed reality both visible and real. As Sutherland argued: "The ability to put motion into the drawings suggests that it would be exciting to try making cartoons."[560] Sutherland noted the potential of

559 Ibid, 107.
560 Ibid, 131.

Sketchpad for animated graphics,[561] particularly in the movie industry.[562] Deborah Douglas, the Curator of Science and Technology at the MIT museum asserted that Sketchpad gave birth to the animation industry through its cartooning capabilities.[563] The following statement by Johnson illustrates the animation capabilities of Sketchpad – as he stated:

> The new transformation is applied to the drawing and a new display is painted on the scope screen. The program continually samples the knob position; as long as the operator continues to turn the encoder, the process repeats. The cycle is fast enough for simple drawings to give the illusion of a moving picture. The part moves relative to two of the three possible axes of rotation in three dimensions as the picture is rotated about one of the orthogonal scope axes.[564]

The rapidly changing drawing on the Sketchpad window created the illusion of an animated picture. The "picture sequence narrative" feature in Sketchpad followed the tradition of the flip books patented by the English printer John Barnes Linnett in 1868.[565] Flip books gave life to cartoon characters, and were considered to be optical tricks, giving the illusion of 'magic'.[566]

In Johnson's dissertation, he explained that even though shading was a necessary component in perspective drawing, it was not integrated into Sketchpad because of difficulties in programming. Johnson gave an example of a movie cartoon that was effective in communicating depth with the use of minimum shading, and stated: "One does not normally have a difficult time determining depth relations when viewing a movie cartoon which uses little of the shading effect."[567]

Licklider hoped that the future of the interactive cathode ray tube would be developed further so that "school children discover that interactive computing is much more fun than watching television."[568]

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[561] The creation of moving pictures began in the late 1800's and continues to evolve with the advancement of technology. The term *animation* means "a way of bringing things to life," and Sutherland's Sketchpad invention belongs to the history of animation. Chad Gregory Walker, Eric Walker, and Jani Kajala, *Making a Game Demo : From Concept to Demo Gold* (Plano, Tex.: Wordware, 2005), 205.

[562] Julie A. Jacko and Andrew Sears, *The Human-Computer Interaction Handbook : Fundamentals, Evolving Technologies and Emerging Applications* (New York, N.Y. ; London: Lawrence Erlbaum Associates, 2008), 5.

[563] Sito, *Moving Innovation: A History of Computer Animation*, 1.

[564] Johnson, "*Sketchpad III: A Computer Program for Drawing in Three Dimensions*." 330.

[565] Scott Higgins and Sara Ross, "Archival News," *Cinema Journal* 45, no. 1 (2005), 123.

[566] David Ebert, *Teaching Children Mathematics* 8, no. 8 (2002), 496.

[567] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." 16.

[568] Licklider. "User-Oriented Interactive Computer Graphics." 90.

The games and fairytale worlds that were created within Sketchpad's space were viewed through the Sketchpad apparatus. Shannon also referenced Carroll's Alice in the development of computer programs in his own work. In an article entitled *Scientific Aspects of Juggling,* Shannon quoted from Carroll's novel *Through the Looking Glass*, saying that: "Things never fall upwards, you know. It's a plan of my own invention [to make objects fall upward using the computer.]"[569]

Sutherland also described Sketchpad's representations as going beyond the physical constraints of the real world, such as the physical constraint of gravity that gives weight to physical objects causing them to fall toward the ground when dropped. In a Sketchpad representation, the human user can create a world where objects fall toward the sky when dropped, instead of downward toward the ground.

On the interface, a fragment from real life is represented, and appears as a seamless experience. This representation, though appearing complete and seamless, is in fact both fragmented and limited to the capabilities of the computer. The mimicry in the game and the Sketchpad interface corresponds with the real and is a modeled process that is partial and fragmented.

Like the player that accepts the limitations of the rules of a game to gain the freedom of game play, so the user of the Sketchpad system is confined to a fragmented humanity to gain the augmentation that is produced by the machine. Hookway argued that this fragmented humanity represented on the computer interface follows Plato's allegory of the cave. As the media theorist McKenzie Wark explains, the game does not obscure the real as being mere shadow play, but rather conditions it.[570] Based on the assumption of Plato's allegory of the cave, the gamer assumes that there is a more real world beyond the game space of the interface.[571] The Sketchpad interface binds the human user and the computer through the control of its mediating power, and it is this drawing together of human and machine into a single system that was

[569] Claude Elwood Shannon. *Claude Elwood Shannon: Collected Papers* (New York: IEEE Press, 1993), Introduction xix.
[570] McKenzie Wark. *Gamer Theory.* (Harvard University Press, 2009), 19.
[571] Hookway, *Interface*, 39.

termed by the time of the Second World War as being a *man-machine system*. For this reason, Hookway argued that control is the primary product of the interface.[572]

The distinction between real life and fiction becomes relatively less important to the action itself. This concept follows anthropologist Clifford Geertz'a description of culture as an "acted document," of which the thing to ask is what it is in the occurrence of the act itself is being said.[573]

Like Sutherland's winking girl, the computer scientist Alan Turing also described the computer as a deceitful 'other', playing a game with the human user. A significant event in the early Human Computer Interaction was a hypothetical test invented by Turing. The *Turing Test*, described in an essay titled *Computing Machinery and Intelligence* that was published in 1950, addressed the question of machine intelligence by a game that Turing called the *imitation game*. Turing's game is played with three people, a man, a woman, and an interrogator who may be of either sex. The interrogator, who is in a different room, must determine the gender of the other two players from the answers the other two players give in response to questions put by the interrogator. All questions and answers are communicated through writing. Turing then replaced one of the two players with a machine, and stated: "We now ask the question, what will happen when a machine takes part of A in this game? Will the interrogator decide wrongly as often when the game is played like this as he does when the game is played between a man and a woman? These questions replace our original – can machines think?"[574]

In 1983, Sutherland built a legged locomotion that was meant to imitate a living organism that resembled an insect. Sutherland's machine was designed to walk, and was large enough to sit and ride upon. It was constructed from half a ton of steel, had hydraulic cylinders to move on six legs, a gas engine to run the hydraulic pumps, and a computer to control it. Shannon, who admired robots, came to visit Sutherland to see this machine and wrote a "little ditty" about it:

Higgledy Piggledy

Ivan E Sutherland

[572] Ibid, 40.
[573] Ibid, 38.
[574] Alan Mathison Turing, "Computing Machinery and Intelligence," *Mind: a quarterly review of psychology and philosophy*. LIX, no. 236 (1950), 433.

Built a huge cockroach

Twelve horse power clout.

But the roach

Waxing Vengeful

From previous roach genocide

Hexapodiacally

Stamped Ivan out[575]

Shannon himself was known as a "trickster" and the inventor of many playful automata. The journalist Anthony Liversidge described Shannon's personality thus: "He laughs often, and is variously playful as a gadgeteer and a prankster. He is vividly remembered at Bell labs for riding a unicycle down its long corridor and back again, juggling all the while."[576]

Sutherland used Sketchpad to make a drawing of a stick figure riding a bicycle to amuse visitors who came to see his invention, remembering that: "Doing this on the computer display amused many visitors…[for example] a stick figure could be made to pedal a bicycle by appropriate application of constraints."[577]

According to the Surrealist artist Kurt Seligmann, historically the juggler is identified as having cosmic powers, "he mimicked wonders by his dexterity, and was a promoter of skepticism."[578] His symbol is placed on the head of the Tarot cards "to indicate that despite every effort to read order into the world one remains the victim of illusion."[579] In many illustrations of the juggler in Tarot cards, the figure is often represented holding a wand. The wand is a device

[575] Frenkel, "An Interview with Ivan Sutherland." 716.
[576] Shannon, *Claude Elwood Shannon: Collected Papers*, Introduction xix.
[577] Sutherland, "Sketchpad: A Man-Machine Graphical Communication System." 132.
[578] Kurt Seligmann, *Magic, Supernaturalism, and Religion* (New York: Pantheon Books, 1973), 281.
[579] Ibid, 281.

that reflects the juggler's connection with the cosmos and "denotes that he has been given the power to consult the oracle."[580]

Parallels between the juggler's wand and Sketchpad's light pen can be made through Roberts' invention called the *Lincoln Wand*.[581] In 1966, Roberts introduced the *wand* as a substituting device for the light pen.[582] Roberts' wand that was also used to make rubber band lines in Sketchpad was faster and more powerful than the light pen.[583] Through the Lincoln wand, Sketchpad's user became a magician performing magic tricks with the computer.[584]

Rubber Band Line Trick

As mentioned previously, Sutherland described the new line drawing in Sketchpad as a rubber band line. This new line facilitated cooperation between human and computer in the process of its making. (See Figure 26) Sutherland's rubber band line may also be viewed as belonging to the tradition of rubber band tricks.[585] A rubber band trick is an inexpensive demonstration that is meant to arouse curiosity and fool spectators.[586]

[580] Ibid, 281.
[581] Roberts, "The Lincoln Wand."
[582] Roy S. Kalawsky, *The Science of Virtual Reality and Virtual Environments* (Wokingham Addison-Wesley, 1994), 149.
[583] Roberts. "The Lincoln Wand."224.
[584] Many contemporary researchers try to use "quantitative science" as an explanation to technological innovations and deny the existence of magic claiming that magic belongs to a tradition that ended with the Renaissance. However, the source of current technology and innovations such as Sketchpad cannot be traced back "quantitative science." Therefore, we are left with the mysterious explanations of the past to understand Sketchpad's representations. Ioan P. Culianu. *Eros and Magic in the Renaissance* (Chicago: University of Chicago Press,1987), Introduction xvii.
[585] Evidence of the connection between rubber and games can be traced back to 1492 when Columbus came to the New World and found the native Indians already playing with rubber balls that they had made. The term *rubber* was introduced in 1770 when an English scientist used a hardened piece of latex to erase a pencil mark by rubbing with applied pressure. In addition to rubber balls, the native Indians made rubber bottles by applying layers of latex on clay molds and breaking out the clay after the rubber had dried. Another Englishman, in the 1830's, invented rubber bands by cutting up rubber bottles into rings. The invention of the rubber band opened up new kinds of toy making, such as the rubber band powered paddleboat. Francis E. Abernethy. *Texas Toys and Games* (University of North Texas Press, 1997), 36.
[586] William E. Mitchell. *Novelties*. Vol. 127. Popular Science (New York: Bonnier Corporation, 1935), 63.

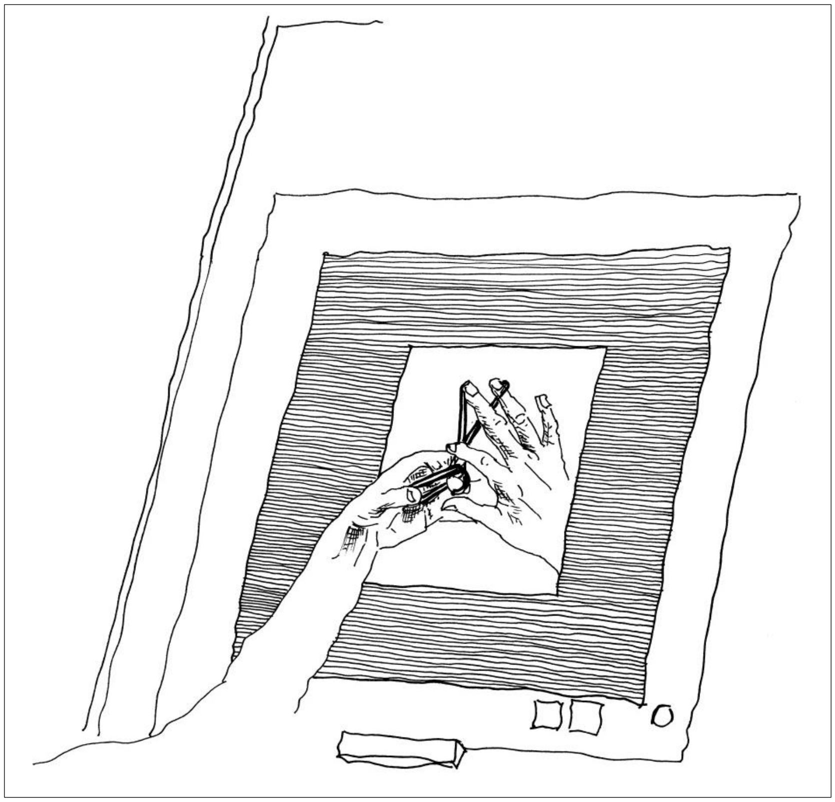

Figure 26: Rubber Band Trick with Sketchpad. (Drawn by the author)

For example, in a rubber band trick a person may change a rubber band from the first and second fingers to the third and fourth, quickly without detection by anyone, "like magic."[587] In Sketchpad, the human user creates rubber band lines with the computer. Through this human-computer symbiosis, both entities collaborate in making the rubber band line drawing. Magicians use rubber bands to deceive spectators in a magic show.[588] Sutherland's animated drawings of the winking girl and the figure riding a bicycle can be understood as tricks like the rubber band tricks.[589]

Licklider described the magical properties of interactive computer graphics when he compared it with a "magic lantern," he stated, "My conclusion … is that now is the time to push forward with research in the areas of computer graphics that people call expensive, sophisticated,

[587] Frank Pfefferle, *Amateur Mechanics*, ed. Albany Times Union. Popular Mechanics (New York: Hearst Magazines, 1913), 760.
[588] John Mulholland, *Mulholland's Book of Magic* (Dover, 2001), 68.
[589] Sutherland, "*Sketchpad: A Man-Machine Graphical Communication System*." 132.

esoteric, and exotic [because] If we do not push forward with research in those areas now, we shall find ourselves with a magic lantern that we don't know how to rub."[590]

Sketchpad's Tic-Tac-Toe Game

Licklider was able to predict much of the contemporary computing world because he combined his understanding of the technology of the computer with his understanding of people and social activities, such as playing games. To understand Licklider's vision, researchers in the field of interactive computer graphics must also examine methods from Licklider's psychology and other social sciences as well.[591]

There is a connection between the *Ping-Pong game*,[592] and Licklider's *man-computer symbiosis.*[593] In his paper titled *The Computer as a Communication Device,* published in 1968, Licklider envisioned another future for his man-computer symbiosis that went beyond the one-on-one interaction between the human user and the computer to include a third person. In this new situation, the computer would play the role of intermediary and would pass on messages back and forth between both human users. Licklider described this situation as "face to face through a computer."[594]

According to Licklider, "Men will be able to communicate more effectively through a machine than face to face."[595] Licklider visualized this new communication system with a "mental image of the ping-pong game. Successful communication between machine and human is the alternation of answers; unsuccessful communication, the absence of any answer characteristic of an overload."[596] To illustrate his point, Licklider included a comic-book drawing

[590] Licklider, "A Picture Is Worth a Thousand Words: And It Costs." 621.
[591] Guzdial Mark, "Human Computing: A New Degree for Licklider's World," *Commun ACM* 56, no. 5 (2013), 34.
[592] Ping-pong or table tennis is a game in which two or four players hit a lightweight ball back and forth using a table tennis racket. The game takes place on a table divided by a net. Play in this game is fast and demands quick reactions. Senaida Lefler, *A Beginners Guide to Table Tennis: Ping Pong* (United Kingdom: Sam Enrico, 2014), 20.
[593] Erkki Huhtamo, *Media Archaeology: Approaches, Applications, and Implications* (Berkeley: University of California Press, 2011), 176.
[594] J. C. R. Lickleder and Robert W. Taylor, "The Computer as a Communication Device," *Science and Technology* (1968), 25.
[595] Ibid, 21.
[596] Huhtamo, *Media Archaeology: Approaches, Applications, and Implications*, 177.

that consisted of both human and nonhuman components engaged in a game of ping-pong. (See Figure 27)

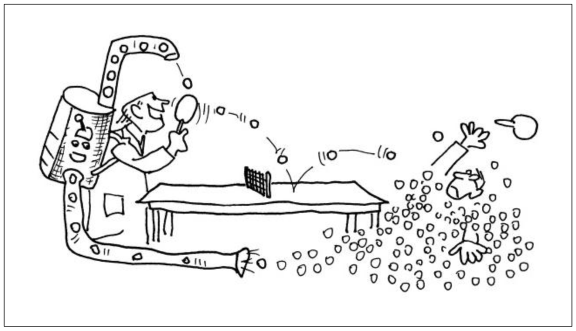

Figure 27: Drawing after Roland B. Wilson's 'Illustration of Licklider's Optimized Interaction.' (Drawn by the author)

In his Sketchpad III thesis, Johnson included a representation of the game tic-tac-toe. As he stated: “Although a somewhat frivolous application, the three-dimensional tic–tac–toe game illustrates one of the dynamic qualities of the [Sketchpad III] system ... Surely the experienced player of conventional tic–tac–toe would be overwhelmed at the extension into the third dimension.”[597] (See Figure 28)

[597] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." 36.

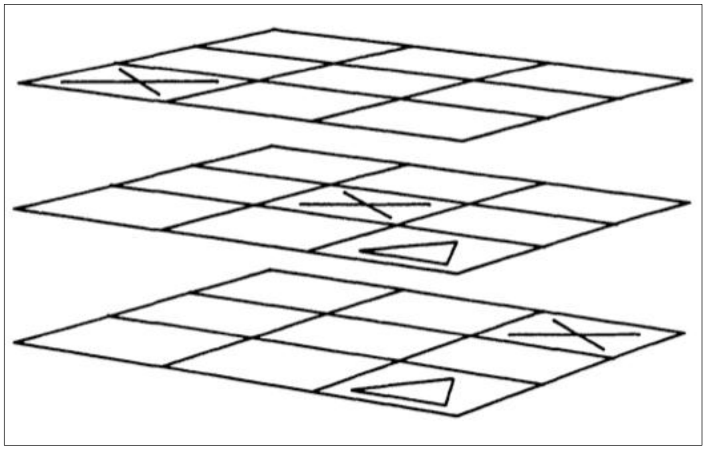

Figure 28: Three Dimensional Tic-Tac-Toe, Timothy Johnson, “Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer” (Massachusetts Institute of Technology, 1963), 36. (By courtesy of MIT)

The game of Tic-Tac-Toe is played on a three-by-three grid. The computer player chooses a mark while the human player uses the other mark. The players take turns placing their mark on an empty cell. When a player manages to create a horizontal, vertical, or diagonal row of three marks, he wins the game. When all cells are filled and a row is created, the game ends in a draw.[598]

The concept of playing Tic-Tac-Toe with the computer can be traced back to Alan Turing’s ideas on using a computer to play chess. In his paper titled *Computing Machinery and Intelligence* that was published in 1950,[599] Turing introduced the concept of playing chess with the computer. Turing identified chess as a good starting point to advance computing research, and estimated that computers would be able to beat human chess champions by about 1957.

[598] Jacob Habgood and Mark Overmars, *The Game Maker's Apprentice: Game Development for Beginners* (New York: Apress, 2006), 245.
[599] Turing, "*Computing Machinery and Intelligence*."

However: “Eventually, computers were built that could beat human chess champions, but it took 40 years longer than Turing predicted.”[600]

Turing imagined the computer player to be the author Helen Keller (1880-1968). Keller was an American author who was blind and deaf. With the help of her tutor Anne Sullivan, Keller during her childhood years learned to use her other senses to communicate with others. Through the method of reward and punishment, Sullivan taught Keller *finger-spelling* which is the sign language that deaf people use. With fingers, one is able to trace the letters that make up each word into the palm of someone’s hand. [601] Turing stated that:

> Helen Keller shows that education can take place provided that communication in both directions between teacher and pupil can take place by some means or other.”[602] And “instead of trying to produce a program to simulate the adult mind, why not rather try to produce one which simulates the child’s? If this were then subjected to an appropriate course of education one would obtain the adult brain… Our hope is that there is so little mechanism in the child-brain that something like it can be easily programmed.[603]

Turing believed that computer “intelligence is not predicated on vision” and should extend to include other senses such as touch.[604] He claimed that educating the child Keller was similar to educating a “child-machine.” He went on:

> We normally associate punishments and rewards with the teaching process. Some simple child-machines can be constructed or programmed on this sort of principle. The machine has to be so constructed that events which shortly preceded the occurrence of a punishment signal are unlikely to be repeated, whereas a reward-signal increases the probability of repetition of the events which led up to it.[605]

Turing described this process of educating the “child-machine” through reward and punishment as being emotionally exhausting. He then turned to another method that was less painful for the

[600] Douglas Hofstadter and Christof Teuscher, *Alan Turing: Life and Legacy of a Great Thinker* (Berlin: Springer, 2004), 168.
[601] Sandra H. Shichtman, *Helen Keller : Out of a Dark and Silent World* (Brookfield: Millbrook Press, 2002), 15.
[602] Alan R. Anderson, *Minds and Machines* (Englewood Cliffs: Prentice Hall, 1964), 27.
[603] Ibid, 26.
[604] Robert Epstein, Gary Roberts, and Grace Beber, *Parsing the Turing Test: Philosophical and Methodological Issues in the Quest for the Thinking Computer* (New York: Springer, 2008), 174.
[605] Anderson, *Minds and Machines*, 27.

"child-machine" that "would probably feel very sore" by the repetition of the "blow." This other "unemotional channel of communication" was in the form of a "symbolic language." Ultimately, the objective of the learning process was to arrive at "a form of behavior which will satisfy the teacher."[606] Alan Turing dreamed that his "child-machine" would learn "to understand and speak English." And eventually compete with him in a "game of chess."[607]

Shannon had similar ideas about playing a game of chess with a computer which he presented at a conference in 1949 and that was published in the following year.[608] Shannon's paper titled *A Chess-Playing Machine* that was published in 1950,[609] described the invention of a "chess machine" that makes it possible to set up an "electronic computer" to play a game of chess with a human.[610] According to Shannon, the obedient chess machine "does only what it has been told to do. It works by trial and error, but the trials are trials that the program designer ordered the machine to make… the machine does not, in any real sense, go beyond what was built into it."[611]

Connections between Shannon and Turing's ideas about using a computer to play chess are not entirely clear. Turing met Shannon at the Bell Laboratories in the United States in 1943, and they talked about computers in the context of intelligence. In 1947, Turing gave a talk to the London Mathematical Society, that was not published until several years later, where he referred briefly to the possibility of using a computer to play chess and said of Shannon that "he tells me that he has won games playing by rule of thumb; the skill of his opponent is not stated." However, when Turing's ideas on using a computer to play chess were published in 1950, no mention is made of Shannon's work.[612]

[606] Ibid, 30.
[607] Ibid, 30.
[608] Barry Cooper and Van Leeuwen, *Alan Turing: His Work and Impact* (Oxford: Elsevier, 2013), 623.
[609] James R. Newman, *The World of Mathematics* (London: Novello, 1960), 124.
[610] Ibid, 125.
[611] Ibid, 133.
[612] Cooper and Leeuwen, *Alan Turing: His Work and Impact*, 623.

Sketchpad's Looking Glass

As mentioned in previous chapters, in Sutherland's description of Sketchpad's renderings, the dafter controlled the representation that was created on the CRT's virtual canvas and had the choice to render a space that corresponded to the real world, or to render an entirely invented space that has no reference to the real world. The CRT monitor in Sketchpad combined the concepts of Descartes Cartesian space with Renaissance linear perspective construction to create fictional spaces. Therefore, Sketchpad was an extension of linear perspective, and through the electronic computer, Alberti's concept of constructing space according to the principles of vision and mathematics was further strengthened.

Licklider appreciated graphics and considered graphics to be a critical component to human-computer symbiosis. He believed that "humans are visual animals," and that the human eye was a "high-bandwidth data channel" capable of absorbing information … [and able to] "recognize patterns and sense complex relationships at a glance."[613]

In Sutherland's reference to Alice and the computer's mathematical wonderland,[614] the dividing element between the perceiver and the representation was the computer screen. In Carroll's *Through the Looking-Glass*, the mirror that separates the real world from the invented world transforms into a screen or a veil. While Alice is dreaming, she crosses over to the other side of the looking glass by passing through it as it transformed into a veil, Carroll's Alice described:

> You can just see a little peep of the passage in Looking-Glass House, if you leave the door of our drawing-room wide open: and it's very like our passage as far as you can see, only you know it may be quite different on beyond. Oh, Kitty, how nice it would be if we could only get through into Looking-Glass House! I'm sure it's got, oh! Such beautiful things in it! Let's pretend there's a way of getting through into it, somehow, Kitty. Let's pretend the glass has got soft like gauze, so that we can get through. Why, it's turning

[613] Waldrop, *The Dream Machine: J.C.R. Licklider and the Revolution That Made Computing Personal*, 255.
[614] Sutherland, "The Ultimate Display."

> into a sort of mist now, I declare! It'll be easy enough to get through. She was up on the chimneypiece while she said this, though she hardly knew how she got there.[615]

Carroll's Alice lived in Sutherland's Sketchpad world, and Sutherland imagined looking at her through "a looking glass into a mathematical wonderland."[616] Lewis Carroll wrote his novels *Alice's Adventures in Wonderland* and *Through the Looking-Glass* for his beloved young Alice Liddle, who was the daughter of the dean of Oxford University's Christ Church where Carroll taught mathematics. Alice's parents separated her from Carroll when they found out he had the desire to marry her someday.[617] Through his novels, Carroll created a dream world for his young Alice. In some instances in this world, Carroll represented himself in his story as the "White Knight" that "waves good-bye to Alice, as she moves to the final square of the chessboard to become queen, the scene [represented the White Knight's] final sad parting with the only child-friend he truly loved."[618]

The philosopher Hurbert Damisch questioned the role of the mirror as either a tool for constructing perspective or for its illusionistic properties.[619] Alberti dedicated his treatise *On Painting* to the Renaissance architect Brunelleschi, whom he acknowledged as the inventor of the single-point perspective.[620] According to the Renaissance architect, Antonio Averlino, known as Filarete:

> If you should desire to portray something in an easier way, take a mirror and hold it in front of the thing you want to do… Truly, I think that Pippo di Ser Brunelleschi discovered perspective in this way…. You can say that it is false, for it shows you a thing that is not. This is true; nevertheless it is true in drawing, for drawing itself is not true but a demonstration of the thing you are drawing or what you wish to show.[621]

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[615] Lewis Carroll and Gardner. *Alice's Adventures in Wonderland amd through the Looking Glass* (New York: C. N. Potter, 1960), 131.
[616] Sutherland, "The Ultimate Display."
[617] Carroll and Gardner, *Alice's Adventures in Wonderland & through the Looking Glass*, 7.
[618] Ibid, 7.
[619] Friedberg, *The Virtual Window: From Alberti to Microsoft*, 15.
[620] Alberti, *On Painting*, 34.
[621] Filarete and John R. Spencer. *Filarete's Treatise on Architecture* (New Haven: Yale University Press, 1965), 305.

In the biographer Antonio Manetti's documentation of Brunelleschi, the author reminded readers that in a perspectival painting, the painter determines a fixed point from which the painting must be seen; for Brunelleschi, that viewing hole in the panel *peephole* was the fixed point determined for the viewer.[622]

Brunelleschi used a mirror to create a peepshow that would deceive the viewer and give a convincing illusion of depth from a picture painted on a flat surface. The mirror used in Brunelleschi's peepshow was essential for completing the deception and convincing the observer of the depth in the painting, similar to the role of the mirror in convincing Alice of the existence of another world through the looking glass. Brunelleschi used the mirror as a tool to aid in creating an illusion of another world in a fantasy. (See Figure 29)

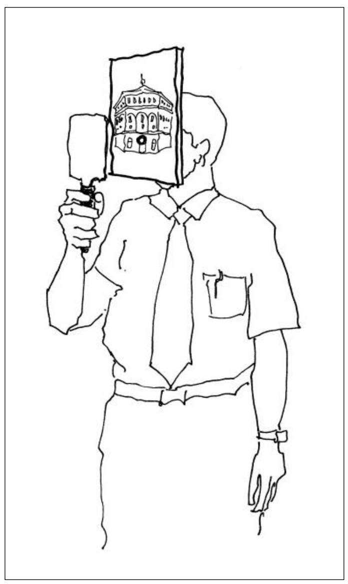

Figure 29: Brunelleschi's peepshow demonstration. (Drawn by the author)

Furthermore, Manetti tells the story of *The Fat Woodworker*, a cruel practical joke devised by the prankster Brunelleschi played on an unsuspecting friend and woodworker named

[622] Lindberg, *Theories of Vision from Al-Kindi to Kepler*, 149.

Manetto.[623] One of the most important moments in the story is when Manetto wakes up in his room and attempts to separate dreams from reality by looking into a mirror. There are parallels between the prank, the peepshow and Sketchpad. The playfulness of the peepshow lay in its ability to give the illusion of truth in a painting. And in Sketchpad, the playfulness lay in its ability to give the illusion of truth, but of another world. The user of Sketchpad becomes the architect of the other world and can manipulate logic to create fantasy. As mentioned earlier, Sutherland's *head-mounted display* invention solved the "windowing" problem in Sketchpad's CRT monitor by surrounding the perceiver with two-dimensional images that correspond to images one would see in the real world.[624]

Like Brunelleschi's peepshow demonstration, Sutherland's Sketchpad and head-mounted display are also peepshow demonstrations. (See Figure 30)

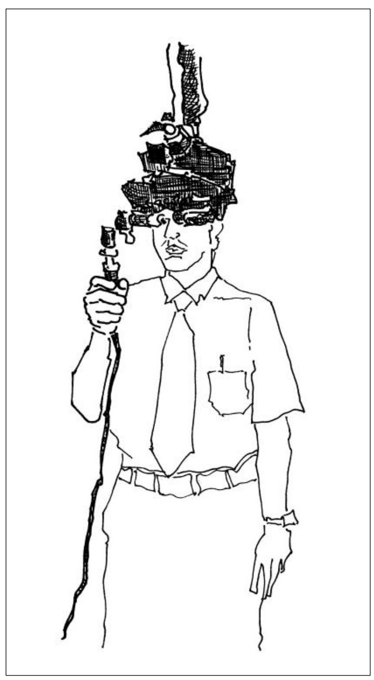

Figure 30: Sutherland's peepshow demonstration. (Drawn by the author)

[623] Antonio Manetti, Robert L. Martone, and Valerie Martone, *The Fat Woodworker* (New York: Italica Press, 1991), ix.
[624] Sutherland, "*A Head-Mounted, Three-Dimensional Display*." 757.

Chapter Nine: Sketchpad and Descriptive Geometry

A closer look at Sutherland's childhood identified a previous knowledge about technical drawings from his father's profession as a civil engineer. This past experience with his father was revealed in an interview conducted by the science reporter Karen A. Frenkel who interviewed Sutherland in 1989. Frenkel asked Sutherland: "How did you come up with the idea for Sketchpad? No one had ever done anything like that before." And Sutherland replied:

> I had been interested in drawings, mechanical drawings in particular, since a very young age. My father was a civil engineer, and I used to look at his blueprints and try to understand what they meant, and what was important in them and what wasn't. So I was able to read mechanical drawings before I ever entered high school. When the opportunity came to use a suitable computer, it seemed the most natural thing to make drawings with it.[625]

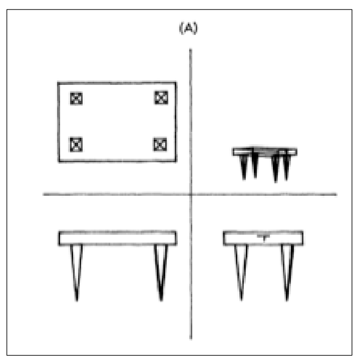

Figure 31: Descriptive Geometry layout with one perspective view, "Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer" (Massachusetts Institute of Technology, 1963), 25. (By courtesy of MIT)

The drawing layout of the three-dimensional expansion of Sketchpad mimicked the established three-view orthographic projection of the third angle projection system of descriptive geometry that is commonly used in America for technical drawing. According to Coons: "In Sketchpad III, as reported in the paper by Johnson,[626] we have a means for drawing and

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[625] Frenkel, "An Interview with Ivan Sutherland." 712-713

[626] Coons is referring to: Johnson, T. E., "*Sketchpad III, A computer Program for Drawing in Three Dimensions*," *Proceedings of the Spring Joint Computer Conference*, Detroit, Michigan, May 21-23, 1963.

manipulating figures in three-dimensional space. This is of course essential to the designer of mechanical or structural devices and objects."[627] (See Figure 31)

For engineers, Sketchpad's descriptive geometry layout was effective in accurately representing the actual geometric shapes of objects and their characteristics in a graphic visual form.[628] The development of Johnson's Sketchpad III drawing layout was made possible through the cooperation of Sutherland and Roberts; he stated, "Special thanks go to … Ivan E. Sutherland and Lawrence G. Roberts for their patient instructions and suggestions on how best to use the TX-2, and for the computer subroutines and programs they unselfishly provided which greatly accelerated this research."[629]

According to Johnson, "The orthogonal projection system is the familiar tool of descriptive geometry—the field of graphics describing a three-dimensional object on a two-dimensional surface. Because of years of experience using descriptive geometry, work began with pen and paper methods in mind."[630]

Through the familiar layout of descriptive geometry in Sketchpad III, the drafter was supposed to believe that solid objects could be represented on the computer's interface in a manner so similar to the drafting table that the transition from the traditional paper on drafting table to the computer's screen would be easy. Coons stated:

> Sketchpad 3 was developed by Timothy Johnson, who, at M.I.T., used the basics of Sutherland's Sketchpad and built on them. In his system the face of the cathode ray tube is divided into four quadrants: one quadrant is for the plan, one for the front view, one for the side view and one for the perspective view of any object one might want to draw. If the plan and the two elevations are drawn, the perspective view of the object will 'automatically' appear in its quadrant. Likewise, the consequences of any change the designer makes with his light pen in any one of the four quadrants are 'automatically' shown in the other three quadrants.[631]

The CRT window displayed graphical images of the three-dimensional object in four views by displaying one in each quadrant of the CRT screen. A perspective view of the object appears in

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[627] Coons. "*An Outline of the Requirements for a Computer-Aided Design System*." 303.
[628] Riccardo Migliari, "Descriptive Geometry: From Its Past to Its Future," *Nexus Network Journal* 14, no. 3 (2012), 555.
[629] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." vi.
[630] Ibid, 19.
[631] Coons. "*Computer-Aided Design*."12.

the upper right quadrant, and three orthogonal views appear in the remaining quadrants: top view in the upper left quadrant of the screen, front view in the lower left quadrant of the screen, and a side view in the lower right quadrant of the screen.[632] Johnson described the importance of including a perspectival view and three projected related orthogonal views to represent the object on the CRT window in the following statement on Sketchpad III:

> Perspective gives the illusion of three dimensions by supplying the familiar convergence of lines as they recede from the viewer. A single perspective view of an unfamiliar object does not convey visually all the correct information either; for example, are the receding lines parallel or do they actually converge? Hence at least one other complementary view is necessary. Three projectively related orthogonal views were chosen for the complementary function. There are several reasons for this choice:
>
> a) Those three views completely describe a straight line in three dimensions.
>
> b) Three ninety-degree rotations of the part are simultaneously in view, reinforcing depth perception.
>
> c) Many users of Sketchpad III were uncomfortable sketching in perspective and preferred the orthogonal system used by most draftsmen.[633]

As a result, the design of Sketchpad III's interface, in particular the views selected to represent an object in three-dimensions, was primarily concerned with the rendering of an optically true representation from a singular perspective, giving the illusion of depth through the convergence of lines that recede from the viewer. This perspective was not meant to convey visually correct information about the object represented, or meant to be used by the drafter in the drawing process.

The three orthogonal views colluded to communicate visually accurate information about the object represented and consequently were easier to draw in. They helped to complement a more accurate perspective, unlike the situation where convergent lines failed to describe a straight-line object in three dimensions. And while an axonometric drawing may have appeared to be a suitable alternative to the division of the Sketchpad window into four views, having all three sides of the object drawn and displayed in one drawing, the axonometric drawing would still need the drafter to have the ability to think and draw in three dimensions – a more difficult

[632] Johnson, "*Sketchpad III: A Computer Program for Drawing in Three Dimensions*." 348.
[633] Ibid, 348.

task than drawing orthogonally. The three views enabled the drafter to draw in two dimensions, whilst the computer program constructed a three-dimensional representation based on the human user's projected drawings, thereby fulfilling its role as a useful symbiotic partner in the drawing process.

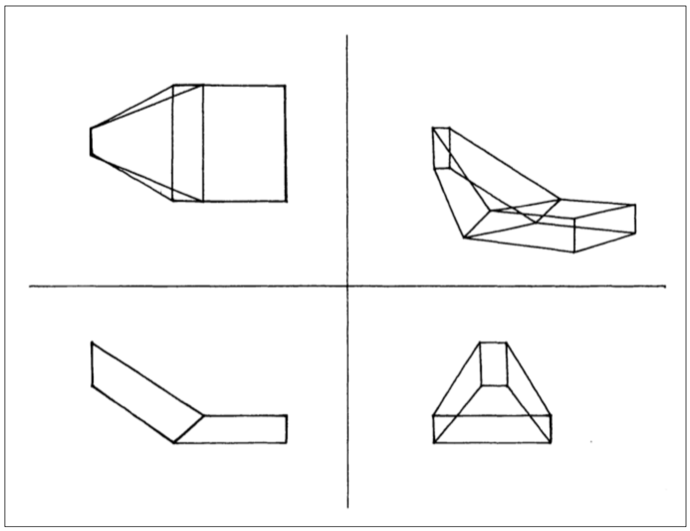

Figure 32: Animated feature in Sketchpad III, Timothy Johnson, "Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer" (Massachusetts Institute of Technology, 1963), 8. (By courtesy of MIT)

Finally, an object effectively represents depth if it is drawn orthogonally and represented in three views simultaneously, with each view presenting a ninety-degree rotation. The Sketchpad system allowed the drafter to rotate the drawing using knobs, and this rotation enabled the presentation of several axes in three dimensions. Some of these axes were fixed with respect to the parts that sloped, in order to eliminate the problem of foreshortened representations that may have conveyed a distorted dimension. Consequently, the Sketchpad III program was designed to create "projectively related auxiliary views" of the sloped parts of the object, in addition to orthographic views.[634]

Descriptive geometry is the foundation for all orthographic drawings and includes the placing of particular oriented views that are defined by projecting points from one view of a three dimensional object, through a rotation of ninety degrees, to construct the remaining surface views object. And: "The man credited with first using descriptive geometry in the development of orthographic drawings of three-dimensional objects is Gaspard Monge."[635]

Monge was born at Beaune in 1746, and died at Paris in 1818. He was the son of a small pedlar, and received his education in the schools of the Oratorians, in one that he subsequently became an usher. He then, attended a military training school at Mezieres, where he received an education in surveying and drawing. It was during his time at Mezieres that he had the opportunity to draw a plan of a fortress using geometrical construction.[636] Instead of producing these plans computationally, as was typically done at the time, he used his geometrical method to solve the problem.[637] Monge's method was so superior to other methods that were being taught at that time that by 1768, Monge was made a professor, on the understanding that his descriptive geometry technique would remain a military secret.[638]

Monge held many important positions in academics during the duration of his life, but it was not until he settled down at Paris, where he was made professor at the Polytechnic school[639] and gave lectures on descriptive geometry that these were published in 1800 in the form of a textbook titled *Geometrie Descriptive.* His treatise *Geometrie Descriptive* contained sections on the theory of perspective and the art of representing three-dimensional geometrical objects in two dimensions.[640]

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[634] Ibid, 330.
[635] David W Melton and Gary Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?," *the Technology Interface Journal* Volume 9, no. 1 (2008).
[636] Leo Gafney, "Gaspard Monge and Descriptive Geometry," *The Mathematics Teacher* 58, no. 4 (1965), 343.
[637] Robert Alan Crabbs, "Gaspard Monge and the Monge Point of the Tetrahedron," *Mathematics Magazine* 76, no. 3 (2003), 194.
[638] W. W. Rouse Ball. *A Short Account of the History of Mathematics* (New York: Dover Publications, 1960), 426.
[639] Monge was an influential educator at the Ecole Polytechnique and was appointed director in 1797 to this school, which remained for many years France's best-known technical school. Crabbs, "Gaspard Monge and the Monge Point of the Tetrahedron."194.
[640] Ball, *A Short Account of the History of Mathematics*, 427.

Monge's development of his descriptive geometry system began with his earlier interest in linear perspective. Around 1768, Monge wrote a treatise on the use of plans and elevations for constructing linear perspective.[641] His approach to perspective was influenced more by the early writers of this subject than by authors closer to his own time.[642] As a result, Monge introduced the idea of a picture plane as a pane of transparent glass and described a perspective image as a section in a visual pyramid. Like many of his predecessors, Monge applied a plan and elevation of the pyramid and the picture plane to determine the corresponding coordinates of the image points of the pyramid.[643] The historian of mathematics Kirsti Andersen believed that compared to the perspective drawing technique of the Renaissance mathematician Piero Della Francesca's presentation of a plan and elevation for constructing perspective images: "Monge's example offers absolutely nothing new. I therefore find it appropriate to say that Monge closed a circle when he incorporated perspective into his descriptive geometry."[644]

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[641] Andersen, *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge*, 709.
[642] Historians describe Monge's descriptive geometry as a drawing system that has a much older history that can be traced back to Vitruvius. Migliari, "Descriptive Geometry: From Its Past to Its Future." 558.
[643] Andersen, *The Geometry of an Art: The History of the Mathematical Theory of Perspective from Alberti to Monge*, 709.
[644] Ibid, 710.

Monge's descriptive geometry method "has led to the development of two similar but different ways of visualizing three-dimensional objects drawn onto a two-dimensional medium: *first angle projection*, and, *third angle projection*."[645] The difference between first and third angle projection is in the arrangement of views, and the terms first and third angle correspond with the notation used in mathematics for the quadrants of a circle.[646] Both methods represent the object's visible and hidden surfaces, but they differ in how the orthographic projection views are rendered relative to the original three-dimensional object being drawn. The *first angle projection* relies on a direct projection method; whereas, the *third angle projection* relies on an indirect projection method.[647] (See Figure 33)

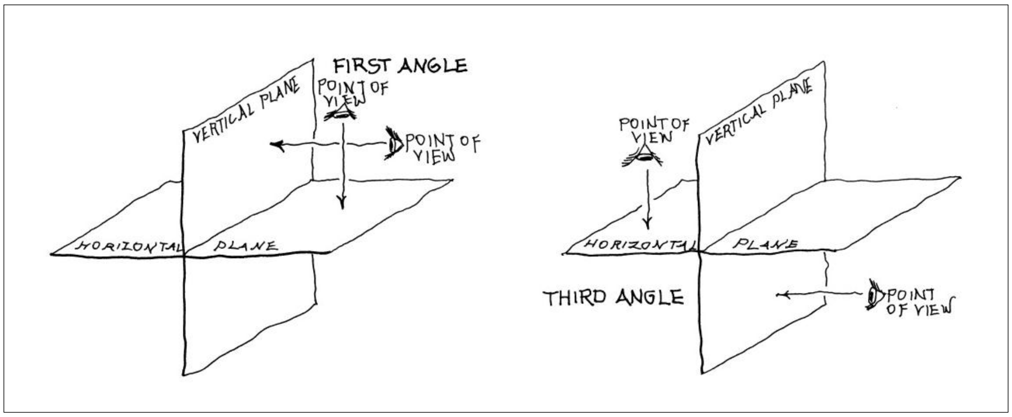

Figure 33: Drawing after L. H. Thornley's the first and third angle projection space. (Drawn by the author)

[645] Melton and Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?."
[646] Colin H. Simmons and Dennis E. Maguire, *Manual of Engineering Drawing: Technical Product Specification and Documentation to British and International Standards* (London: Butterworth-Heinemann, 2012), 25.
[647] Melton and Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?."

In both first and third angle drawing systems, orthographic projection is a means of showing the exact shape of an object by considering its various surfaces in turn.[648] The various surfaces are considered in relation to two surfaces called the vertical plane and the horizontal plane that intersect at right angles to one another. Lines from points on the object are then imagined, traced to a position on the vertical or horizontal planes at right angles: "Consider the object to be situated so that one surface is parallel to the vertical plane and another surface parallel to the horizontal plane."[649]

In the *first angle projection*, the projection of the defining points of each view of the three dimensional object is cast onto the interior walls of an imaginary box surrounding the object. This imaginary box is then unfolded in the direction of the viewer's gaze, and provides the viewer with the orthographic projection views of the object.[650] In the *third angle projection*, the projection of the defining points of each view of the three dimensional object is cast onto the exterior walls of an imaginary box surrounding the object. The defining points of each view of the object that is projected onto the exterior face of the box produces orthographic views of the three dimensional object as the viewpoint is changed by rotation through ninety degree increments about the center of the object.[651]

The *third angle projection* presents each of the projected views of the object in their logical positions relative to the position of the original object being drawn. The top view is positioned directly above the front view, the bottom view is positioned directly below the front view, and the side view is positioned beside the corresponding side of the object.[652] On the other hand, the *first angle projection* does not present the orthographic views of the object in an intuitive and simple way. The *first angle projection* requires the drafter to project the image that is viewed onto the opposite inner surface of the imaginary box that surrounds the object being

[648] An orthographic projection in the x and y plane can be created by drawing an object using x and y coordinates only and ignoring the z coordinates. Similarly, a projection in the *y,z* plane is created by ignoring the *x* coordinate, and in the *x,z* plane by ignoring the y coordinate. As a result, an orthographic projection of an object can be displayed by translating, rotating, and scaling the object so that it represents the required relation to the screen, and then displaying the drawing of the object without regard to the values of the depth coordinates. Mitchell, *Computer-Aided Architectural Design,* 351.
[649] Graham H.W. Andrews. *Technical Drawing in Third and First Angle Projection* (London: Pope Print Timaru, 1983), 40.
[650] Melton and Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?."
[651] Ibid.
[652] Ibid.

drawn. As a result, the placement of the orthographic views is relative to the actual object and requires the viewer to figure out which side of the object does the orthographic drawing represent. For instance, the right side view of the object being represented would appear to the left of the front view instead of to the right of the front view. Intuitively, the viewer would expect the right side view to be placed to the right of the front view; however, the orthographic drawing is drawn onto the inner surface of the box directly ahead of the viewer's gaze. It is this difference that distinguishes *first angle projection* from the *third angle projection* in the production of orthographic views of objects.[653]

The first and third systems of projection used in technical drawing are often referred to as British and American projection respectively.[654] "It is curious that the term British is used because the inventor of the so-called British system was a French mathematician, Gaspard Monge… In Britain, Monge's original ideas were accepted and copied and later adapted to industrial drawing. In America, however, practical considerations appear to have come first because the original ideas were quickly modified for industrial drawing."[655]

In 1816, the American civil engineer Claude Crozet introduced Monge's descriptive geometry to the United States through his position as a faculty of the U.S. Military Academy at West Point.[656] Colonel Crozet, "known today as the Father of Descriptive Geometry in the U.S.A., was a graduate of the Ecole Polytechnique… He was engaged to teach engineering to the cadets at West Point … Crozet's *A Treatise on Descriptive Geometry* was written for use at the Military Academy and was published in 1821. This was probably the first book in English on this subject."[657]

Textbooks on technical drawing that were published in the United States around the time of the Sketchpad invention typically include the use of *third angle projection* drawing practices that was commonly employed by the American engineer.[658] For example, in his book *Technical Drawing*, published in 1942, the architect and professor of mechanical engineering Frederick E.

[653] Ibid.
[654] L. H. Thornley. *First and Third Angle Projection in Technical Drawing* (London: Pitman, 1968), Introduction v.
[655] Ibid, Introduction v.
[656] French authors wrote the "best" textbooks on technical drawing that had been pioneered in Britain. Arnold Pacey, *The Maze of Ingenuity: Ideas and Idealism in the Development of Technology* (Cambridge MIT Press, 1992), 181.
[657] Booker. *A History of Engineering Drawing*, 167.
[658] Melton and Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?."

Giesecke illustrated the differences between the *first and third angle projections* and explained that while there were two drawing methods for creating orthographic drawings, the American engineer must always follow the drawing method of the *third angle projection.* As Giesecke stated:

> This is the American Standard arrangement of views, and while some views may be omitted, as will be shown later, no view should be drawn in any other position. The top view is placed directly above the front view; the bottom view directly below the front view; the right side view, directly to the right of the front view; the left side view to the left of the front view; and the rear view to the left of the left side view. Each view should be thought of as representing the object itself viewed in that position.[659]

While Giesecke explained in his book the availability of two methods for constructing orthographic drawings in descriptive geometry, he clearly specified the drawing system that the American engineer must follow. As Giesecke explained: "The three principal planes of projection are situated at right angles to each other and are known as vertical, horizontal, and profile planes."[660] These "three axes intersect in a point known as the origin of co-ordinates. The four dihedral angles formed by the vertical and the horizontal plane are known, respectively, as the first, second, third, and fourth angles."[661] In the *first angle projection* method, if the object is situated "so that its front and back faces are parallel to the vertical plane of projection, and its top and bottom faces parallel to the horizontal plane of projection, the side faces will be parallel to the profile plane of projection, and the three sets of faces will be shown in their true forms and sizes in their respective projections."[662] These projections "in technical drawing" are known as "front, top, and side views of the object." The remaining views are then obtained by revolving two of the planes into the third plane. "This method of projection is known as first-angle projection, and is used in practically all European countries."[663]

Giesecke explained that in the *third angle projection* method: "If the cube is in the third angle with its faces parallel, respectively, to the planes of projection, the front, top, and side faces of the cube will be shown in their true forms and sizes, in respective views." Revolving the

[659] Frederick E. Giesecke. *Technical Drawing* (New York: Macmillan, 1942), 149.
[660] Ibid, 144.
[661] Ibid, 144.
[662] Ibid, 145.
[663] Ibid, 146.

horizontal and profile planes until they coincide with the vertical plane produces the remaining views of the cube. In this method, the top view is directly above the front view and the right side view is directly to the right of the front view. “This method of projection is known as third-angle projection and is universally used for working drawings in the United States and Canada.”[664]

For many decades, Europe had used the *first angle projection* method in creating orthographic views of three dimensional parts for manufacturing, while in the United States, engineers had opted for the more logical and intuitive method of *third angle projection* and used it in engineering drawing as a general practice.[665]

Prior to the First World War, there was a lack of standardization of engineering drawing conventions. This, however, was not considered problematic so long as the engineers and draftsmen were able to understand how to fabricate the necessary components to make the manufactured product work properly.[666] It was during the First World War that standardization in engineering drawing became necessary to ease the exchange of ideas via engineering drawings between the United States and Europe.[667] Throughout both First and Second World Wars, American and European engineers struggled in communicating with each other because of the differences in engineering drawing, but neither side was willing to admit that the other side had the better method for producing orthographic drawing, and as a result, neither first nor third angle projection was adopted as an international drawing standard.[668]

Sketchpad brought changes to the traditional drafting process. With the introduction of Sketchpad III designed specifically to increase the ease of drawing and reduce the time required to produce drawings, the need for drafters to develop the skills required by their predecessors was minimized. As more powerful graphic programs were developed based on the Sketchpad system, drafters came to rely less on the skills of the past to create the necessary views of parts, and to rely more on the technology of computers to provide structure to their drawings. Because it was invented by American engineers and in an American facility in the latter part of the

[664] Ibid, 146.
[665] Melton and Stewardson, "The American Drafter: Why Use 1st Angle Projection in a 3rd Angle World?."
[666] Ibid.
[667] Ibid.
[668] Ibid.

twentieth century, Sketchpad III was designed to mimic the drawing layout of the *third angle projection* that was used in engineering drawing in the United States.

X, Y and Z in Sketchpad

Sketchpad was ideal for descriptive geometry because in a Sketchpad drawing a cross appeared on the computer's screen that represented the reference and starting point of the drawing. In a Sketchpad drawing: "a cross appeared on the computer monitor which could be recognized by the light-pen as the reference and starting point of the drawing. Moving the light-pen in relation to this initiation point allowed one to draw lines in reference to what was being represented on the computer screen."[669]

Through Sketchpad III, the drafter is unaware of the mathematical sequence of creating the drawing because the drafter is dependent on the symbiotic relationship with the computer and is relieved from comprehending the mathematical aspects of the drawing. [670] In constructing a drawing using descriptive geometry, the computer follows a geometric code.[671] Coons believed that the descriptive geometry technique could be an effective method that enables programmers to formulate a systematic solution for creating drawings using algorithms. And it was this feature in descriptive geometry that made it an appropriate drawing system for the computer. Through Sketchpad, descriptive geometry could be viewed as a drawing system that historically expands to include both compass and computer-aided design.[672]

Descriptive geometry operated through Cartesian rationalism by assuming that the x, y and z axes could be rotated synonymously in any direction in the abstract geometric space of the computer. This Cartesian system is suitable for creating engineering drawings because it does not favor a specific axis as a starting point for a technical drawing, rather, the engineer determines the main axis for the drawing based on the component or assembly that will be fabricated from the drawing.

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[669] Rocker, "Interface: Between Analog and Digital Systems." 56
[670] Migliari, "Descriptive Geometry: From Its Past to Its Future." 555.
[671] John Karsnitz, Stephen O'Brien, and John Hutchinson, *Engineering Design: An Introduction* (New York: Cengage Learning, 2012), 136.
[672] Migliari, "Descriptive Geometry: From Its Past to Its Future." 555.

Early in the nineteenth century, architect Jean- Nicolas-Louis Durand[673] introduced Cartesian rationalism into architecture.[674] Durand's method utilized Monge's system for building units to create a descriptive geometry system for architectural modules.[675] The drawing system that Durand created for architectural representation has continued as the preferred architectural drawing convention of the twenty-first century and is today known as section, elevation, and floor plan.[676] Descriptive geometry and the Cartesian grid as a planning system became the dominant planning aide for architects.[677]

From the very beginning the developers of the Sketchpad III system were challenged by the technical aspects of programming the computer to mimic the descriptive geometry system of drawing. Instead, the focus should have been toward how the activities of making drawings engaged the designer mentally and bodily through the design itself.[678] As stated, true creativity in design is achieved through the habitus of drawing.[679] For instance, the habitus of drawing has always been strongly present in hand drawing as the architect experiences the future design of a building and its construction through the making of the drawing.[680]

As stated, for architects, Sketchpad III that evolved from the drafting table eliminated an essential component in architectural drawing – the process of drawing that actually engenders the habitus of architectural practice. This component of traditional drawing practices may not be necessary in engineering disciplines, but it is fundamental to architectural ones.

According to Frascari, architectural drawing is a way of acting out and exploring the built environment because it exists before other tactile experiences can take place. Frascari believed

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673 The French mathematician and philosopher Rene Descartes (1596-1650) successfully connected geometry and algebra. The practical application of his geometric method was attached as an extensive appendix to his treatise titled *Discourse on Method* that was published in 1637.Booker, *A History of Engineering Drawing*, 80.

674 Quincy Quatremère de and Samir Younes, *The True, the Fictive, and the Real: The Historical Dictionary of Architecture of Quatremère De Quincy* (Woodbridge: Papadakis Publisher, 1999), 28.

675 Rocker, "Interface: Between Analog and Digital Systems." 53.

676 Ibid, 53.

677 Ibid, 54.

678 Paul Emmons, "The Mechanization and Automation of Architectural Drawing Practices," (2011).

679 The sociologist Pierre Bourdieu described *habitus* as a durable, transposable system of definitions acquired initially by an individual then is passed on to other individuals to ensure the active presence of past experiences. According to Bourdieu, "The *habitus* – embodied history, internalized as a second nature … is the active presence of the whole past of which it is the product. As such, it is what gives practices their relative autonomy with respect to external determinations of the immediate presence." Pierre Bourdieu, *The Logic of Practice*, trans. Richard Nice (California: Stanford University Press, 1980), 56.

680 Ibid.

that architectural drawings are not photographic or artistic representations; rather, they belong to a category of embodiment that makes architectural ideas possible from the merging of the human brain and bodily experiences.[681] This embodiment, which is essential to *architectural facture*, challenges the Cartesian dualism that has long had an influence upon architecture and architectural drawings.[682] One of the limitations of the Cartesian drawing system is the absence of sensual perceptions and materiality that paper and ink play as part of the making of drawings.[683] Accordingly, Descartes would have found computer drawings to be an equivalent substitution for traditional ink-on-paper drawings.

Durand's Cartesian basis for drawing presumes that the x, y and z axes can be rotated in any direction interchangeably in abstract space."[684] In a Sketchpad III drawing, the status of the horizontal and vertical sections are equal, and the plan of the object represented in the drawing is a top view drawing that is situated in relation to the axis of the Cartesian coordinate system. Unlike the traditional drafting table, the computer drawing is created on a vertical window.

Giving equal status to horizontal and vertical sections in an architectural drawing ignores the architectural plan as an expression of gravity and reduces it to an axis.[685] According to Emmons, when horizontal and vertical become directional axes without the architect's bodily relation to the plan, then the plan becomes a product of extrusion rather than a weight impressed upon the earth through an expression of gravity.[686]

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[681] Frascari, *Eleven Exercises in the Art of Architectural Drawing: Slow Food for the Architect's Imagination*, 5.
[682] Marco Hale Jonathan Starkey Bradley Frascari, *From Models to Drawings: Imagination and Representation in Architecture* (London; New York: Routledge, 2007), 26.
[683] Ibid.
[684] Paul Emmons, "Back to the Drawing Board: Embodiment in Architectural Drawing Practices." 9.
[685] Ibid, 9.
[686] Ibid, 9.

According to Emmons, “architects not only think with drawings, they also think in them.”[687] This is achieved through the upright posture of the architect while drafting on the horizontal drawing table. Through this posture, the architect imaginatively occupies the space between the sky above and earth that is represented in the architectural floor plan that is positioned on the horizontal drafting table.[688] Consequently, an architectural drawing is a double act of embodiment, which includes the drafter’s bodily relation to the horizontal drawing surface and the imagined bodily projection of inhabiting the floor plan of the building design.[689]

Figure 34: TX-2 console area, Timothy Johnson, “Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer” (Massachusetts Institute of Technology, 1963), iv. (By courtesy of MIT)

[687]Ibid, 1.
[688]Ibid, 5.
[689]Ibid, 1.

Unlike the upright vertical drawing screen of the Sketchpad window that did not necessitate that the drafter begin the drawing at any specific starting point on the display, in the architectural horizontal drafting table the drawing typically begins at the bottom of the drawing, at the foot. The architect's foot on the floor mirrors the drawing footprint as the starting point on the drawing. It is this physical posture of the architect during the drawing process that enables the imagined bodily projection into the site of the drawing board.[690]

Licklider also recognized the challenges of using the computer's vertical display and made some attempts to improve computer hardware so that it would accommodate users' needs for a horizontal computer monitor. As he stated:

> All workstation output is heavily visual … While we're at it, we might as well get around to this horizontal versus nearly horizontal versus nearly vertical orientation. I just can't for the life of me understand why we continue to put up with vertical screens. You want a display area that you, as well as the computer, can write upon so that you can write notes to each other… On the subject of horizontal displays, in World War II, there were planned position indicators called PPIs, which were cathode ray tubes – big ones that were oriented horizontally with a horizontal face … Those were very useful displays. I would like to see some of those show up in the computer world.[691]

Licklider then goes on to describe his solution to the problem of the workstation orientation by making the cathode ray tube display swivel. As he noted:

> I was in on the purchase of the very first Digital Equipment, PDP-1, when I worked at Bolt, Beranek, and Newman. Ed Fredkin was the go-between with DEC, and I told Ed that we really wanted a scope that swivels. I think I explained, so that you could put it down and write on it or put it up and use it in the regular way. I went off on a trip and when I came back I asked Ed how the PDP-1 was coming and he said, "Oh great. I think you'll really like the swiveling thing – we've even hired a design consultant." I went to look at it, and, indeed, it swiveled, but … it swiveled the wrong way. [It swiveled from the right to left and vice versa] And so I am still a little frustrated about writing on the cathode ray tube.[692]

[690]Ibid, 6.
[691] Licklider. "Some Reflections on Early History."121.
[692] Ibid, 123.

Licklider believed that the vertical computer screen made it difficult for the designer to comprehend the representation on the screen.[693] As he noted:

> Many times I have heard that layout defended on the ground that users quickly learn to operate the [hand held device] while looking at the screen, but in fact the dissociation … impairs performance significantly in some of the most basic graphic input tasks … obviously, the solution is to put the display down on the desk top and use it as a common medium for both the computer and the user.[694]

Sketchpad and Computer-Aided Manufacturing

Drafters translate sketches of engineers and architects into detailed drawings that are used in manufacturing and construction.[695] Their tasks may include interpreting directions given to them, making sketches, preparing drawings to scale, and preparing drawings of construction details. The future potential of Sketchpad III for creating theses drawings was examined by Johnson who stated that:

> As the system evolves [Johnson referred to Sketchpad III], computers will be applied throughout the design-to-manufacturing spectrum. Design analysis (stress, dynamic, etc.) capabilities will be embraced by the system and operate directly upon and influence the stored graphical information. Manual part programming for numerically controlled production machines can be by-passed. The goal is to decrease the time spent preparing a part for production (lay-out, detail, drafting, etc.) from months to days.[696]

Nowadays, most drafters use computer-aided drafting systems to prepare drawings. These systems employ computer workstations that create a drawing on a television screen. The drawings are stored electronically so that revisions are applied to the drawings easily. Madsen stated: “As technology advances and the cost of systems continues to fall, it is likely that almost all drafters will use CAD systems regularly in the future… Due to advancement in the

[693] "User-Oriented Interactive Computer Graphics." 94
[694] Ibid, 94.
[695] Thomas C. Olivo, Albert V. Payne, and Thomas P. Olivo, *Introduction to Blueprint Reading and Sketching*(Berkshire: Van Nostrand Reinhold, 1983), Preface iii.
[696] Johnson, "*Sketchpad III, Three Dimensional Graphical Communication with a Digital Computer*." 353.

technology used to create drawings, drafters are becoming technicians. The term drafter is being replaced by drafting technician, CAD technician."[697] Coons believed that:

> While designers in engineering, perhaps, are less interested in aesthetics than designers in other fields, all creative designers are involved in a similar process. This design process unfolds something like this: at the beginning, in the design of a device … the designer does not have a very clear notion of what he wants to do. He has only a vague concept, or none at all, of how he will go about accomplishing his task. In this sense, the design process is a learning process during which the designer must learn what the problem is and how to solve it. Within this process of learning there are certain exciting aspects of discovery. But these are interspersed with long tedious periods of rote behavior – sheer unadulterated dull work – noncreative but necessary. It is appropriate to have computers to do this noncreative work so as to leave the designer free for the activities human beings are good at: innovation – the association of hitherto unrelated ideas. The typically human aspect of the design process is invention: the grasping of schemes that are at the beginning vague, tenuous, dream-like, and solidifying them into something tangible that can be looked at, explored qualitatively, and evaluated quantitatively. To the same schemes, one can apply analytical procedures and then, on the basis of these procedures, make more precise judgments. While all activities during the design process up to the application of analytical procedures are humanoid, analytical procedures are essentially not.[698]

In Coons' analysis of the human and mechanical aspects of the creative process in design, he proposed to let the computer, which he also referred to as humanoid, take over where the task becomes repetitious and non-creative. "Humanoids are machines that have the form or function of humans."[699] The term humanoid machines are often associated with automata, robots and androids.[700] Automation is defined as "a mechanical device designed to follow a set of instructions."[701] The earliest automations that the clock and watchmaker Pierre Jaquet-Droz and his sons built,[702] in 1773 were called the *Musicienne*, the *Writer*, and the *Draughtsman*.[703] (See Figure 35) The Draftsman's mechanism enabled it to execute drawings of refinement of Cupid in

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[697] David Madsen. *Engineering Drawing and Design* (Cengage Learning, 2011), 2.
[698] Coons. "Computer-Aided Design." 7.
[699] George A. Bekey, *Robotics: State of the Art and Future Challenges* (London; Singapore; Hackensack, NJ: Imperial College Press; Distributed by World Scientific Pub., 2008), 71.
[700] Jan Plamper, *The History of Emotions: An Introduction*, trans. Keith Tribe, Emotions in History (Oxford: Oxford University Press, 2015), 26.
[701] Kathryn Clay, *Humanoid Robots: Running into the Future* (Minnesota: Capstone Press, 2014), 9.
[702] Pierre Jaquet-Droz was a Swiss born clock and watchmaker. He was renowned for his knowledge and skill in building complex automata. Edmond Droz."From Jointed Doll to Talking Robot," *New Scientist*1962, 39.
[703] Ibid, 39.

his chariot, a butterfly, and the head of Louis XV.[704] Sutherland's Sketchpad was also known as the "Robot Draftsman," as it was later called.[705]

Figure 35: Drawing after Pierre Jaquet-Droz automata called the Draugtsman. (Drawn by the author)

As mentioned in previous chapters, humanoid machines are represented in cultural products, such as novels and films, and are often depicted as developing a relationship with humans.[706] To illustrate his belief on the nature of the relationship between the human and the humanoid in the Sketchpad system, Coons said:

> The interaction between operator and computer goes somewhat like this: the computer says to itself: I think what the boss means is that these two lines should be concurrent. Therefore, subsequently, if the boss pulls the figure apart, the computer will put it back together again. Now the computer has many ways of reassembling the figure. It does not know exactly in what way the boss wants the lines attached, it only knows that it has been told to attach them. So it will choose, automatically, one specific way of attachment and if that turns out to be appropriate – fine. If the operator does not like the decision the

[704] Ibid, 39.
[705] Jon Peddie, *The History of Visual Magic in Computers How Beautiful Images Are Made in Cad, 3d, Vr and Ar* (London: Springer, 2013), 99.
[706] Plamper, *The History of Emotions: An Introduction*, 26.

> computer makes, he can talk with the computer and say: No, I didn't mean that, I meant something else. This is very much like the psychological process called reinforcement. In this case the behavior of a machine instead of an organism is reinforced.[707]

Historically, the etymology of the word *robot* originated from the Slavic word *robota* that is used to refer to slave or forced labor.[708] During the *Architecture and the Computer Conference*, Coons described the future of the computer in aiding architects in their design tasks – as he stated:

> On an architect's scale it will be possible in the near future – perhaps 5 or 10 years from now [statement made in 1964] … to learn how to satisfy human wants, or how to solve problems, where the computer and the man are mutually engaged in the learning creative process – the man as the general of ideas, and the computer as the appropriate slave.[709]

In a journal entitled *Pencil Points: A Journal for the drafting room* published in 1930, a cartoon drawing depicted a male professional calling for an "electrician" to fix a robot "draftsman" who was not following instructions properly.[710] (See Figure 36) Sketchpad's robot draftsman is forced to obey his master, the human operator. Humanoid machines are sort of a mirror image of humans that create them, but "if the machine is too much like a human being, all empathy vanishes and is replaced by disgust."[711] Such unpleasant feelings towards Sketchpad's humanoid can be inferred from Coons' method of correcting the machine's behavior by applying the psychological process called reinforcement.

[707] Coons. "Computer-Aided Design." 9.
[708] Angelo Cangelosi and Matthew Schlesinger, *Developmental Robotics: From Babies to Robots* (2015), 19.
[709] Center, *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 38.
[710] James Noecker, "Here and There and This and That," *Pencil Points: A Journal for the Drafting Room* (1930), 597.
[711] Plamper, *The History of Emotions: An Introduction*, 27.

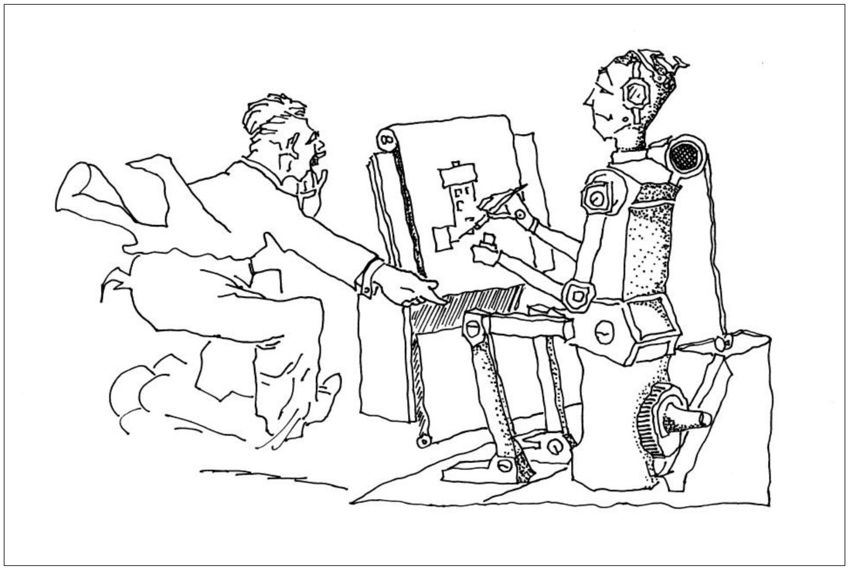

Figure 36: Drawing after James Noecker's 'In Days to Come.' (Drawn by the author)

The Oxford English Dictionary defines a robot as “a machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer.”[712] The concept of 'automatically' is essential to the characteristics of Sketchpad’s robot draftsman because it operates automatically without the direct and continuous control of a person. The automaticity refers to the robot having the capability to integrate input information and select an action to achieve a specific goal.[713] Another important concept in the definition of a robot is programmable by a computer. This means that Sketchpad’s robot draftsman is controlled by computer software programmed by a human expert.

According to Booker: “The Cathode-ray tube and the computer were, in effect, the pencil, the hand and the rule – the brain which controlled them and thought in three-dimensions was outside this arrangement, in the person of the draughtsman who made the original drawing.”[714] Without realizing it, the designer uses bodily cognition during the drawing process to think and work out his designs.[715]

[712] Stevenson and Waite, *Concise Oxford English Dictionary*, 1244.
[713] Cangelosi and Schlesinger, *Developmental Robotics: From Babies to Robots*, 20.
[714] Booker, *A History of Engineering Drawing*, 229.
[715] Emmons and Kassem, "Architect-Computer Symbiosis." 55.

Chapter Ten: Sketchpad and the Industry

The majority of applications that evolved from Sketchpad were developed to service the engineering requirements of governmental institutions and private agencies that prioritized minimizing cost related to labor and construction. Mitchell explained that the earliest architectural drawing software resembled the descriptive system of drafting because the funding for developing these programs came from these institutions.[716] By the time architects became interested in using computer-aided design systems in their practices; these systems had already been well established with little room for adjustments.

As mentioned previously, in 1964, Coons introduced Sketchpad to the architecture community at the *Boston Architectural Center*. It was not until the *American Institute of Architects AIA* urged architects in the academia to raise awareness among the architectural community that the issue of integrating the computer in architectural practice was taken into consideration.[717] Morse Payne, architect and president of the *Boston Architectural Center*, in his *Welcome* address to the conference entitled *Architecture and the Computer* stated that: "The American Institute of Architects informed us that our subject was of the utmost importance, and of great concern to many people. This conference is the first in the United States where our profession shall come to grips with the problem."[718] Payne also argued that:

> The computer seems the most timely, the most urgent, the most serious subject that we could bring to the profession … We are even more startled when technicians tell us that this instrument [the computer] will make a major penetration into our profession within five to ten years, aware as we are that we know so little of its potential and its uses. Our profession is steeped in time-honored traditional methods of approaching architectural assignments, but this machine, a product of our day and our time, might require us to change and approach our task in some new manner… On the national level, the American Institute of Architects informed us that our subject was of the utmost importance and of great concern to many people. This conference is the first in the United States where our profession shall come to grips with the problem. Every other profession had absorbed the computer some five years earlier than our own, and we are the last to pay attention, and indeed, we may have lost an opportunity for leadership, as the computer industry is not

[716] Mitchell. *Computer-Aided Architectural Design*, 15.
[717] Center. "Architecture and the Computer; Proceedings, First Boston Architectural Center Conference." 1.
[718] Ibid, 1.

> directing itself towards our profession, but coming through the back door directly to the building industry, while the architect takes a back row seat.[719]

The development of computer-aided architectural design systems lagged considerably behind the development of computer-aided design systems for engineering. Because the idea of using the computer for architectural design was rejected among architects, and also due to unfamiliarity with the computer and its potential. The main reason, however, was economic, and yet, as computer technology continued to develop and as costs of computer systems decreased, their use gradually became an increasingly widespread reality in practice during the early 1970's."[720] Mitchell described these early applications as being mostly in areas related to the process of building construction and included mechanical calculations, cost estimation, economic analysis, and specification production.[721]

Modifications to already established CAD programs were minimal because with the decrease in hardware price came an increase in software price.[722] By the time architects were able to afford purchasing a computer with its complementing hardware like plotters, architects had to use the same CAD programs that were available for engineers. Another factor that hindered the development of architectural CAD programs was the establishment of *software copyright*.[723] In the 1960's, when communities of academics and researchers conducted a great deal of software development, programmers exchanged information freely, motivated by the desire to enhance programs to better serve user needs.[724] According to Licklider:

> Somebody along the line has invented *closed software.* Back in the early days, software was pretty much a public commodity. If somebody had some that you wanted, you wrote a letter and maybe you sent a tape or maybe IBM cards and you got back the needed software. But then, interest in software mushroomed, and it turned out to be lucrative.

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[719] *Architecture and the Computer: Proceedings, First Boston Architecural Center Conference, December 5, 1964, Boston, Massachusetts*, 1.
[720] Mitchell, *Computer-Aided Architectural Design*.
[721] Ibid, 16.
[722] Larry L. Duetsch, *Industry Studies* (New York: M.E. Sharpe, 2002), 327.
[723] Software Copyright can be owned or transferred. The copyright holder may set the terms for software use, and is the one who can modify or redistribute software. Any change made to the software without software copyright holder permission is copyright infringement and is considered unlawful. Jisuk Woo, *Copyright Law and Computer Programs: The Role of Communication in Legal Structure* (New York: Routledge 2014), 92.
[724] Benedict Atkinson and Brian Fitzgerald, *A Short History of Copyright: The Genie of Information* (Springer, 2014), 103.

> Mainframe software turned out to be very expensive. You know you can pay $50,000 or $100,000 for it. But little programs were still free, until this wave of personal computing made them valuable. I would observe that putting commercial value on programs is a very bad thing for the user. The user wants open software that can be modified and that can participate in a progressive improvement process. It's never right at first, and if the conditions are such that it will be modified in response to user requirements, as in a kind of free academic arrangement, then all goes well. Indeed, if it's very popular software like Lotus 1-2-3, then people at the software companies spend a lot of time and energy making it better, and it gets better. But if it's appealing to a segment of the market, but not to a very rich segment, it can sit around for two or three years without being improved at all, and that is bad.[725]

Initially, computer programs were not protected by copyrights because computer programs were not viewed as a creative work and because the term "copyrighted works" applied to material in a form that others can see and read, a condition that does not apply to work stored in a computer's memory. Eventually, in 1974, Congress established the National Commission on New Technological Uses of Copyrighted Works and the US Copyright Act that recognized copyright in computer programs was established.[726] As a result, it was difficult to significantly alter already existing engineering computer programs for architects in the 1970's because by then these programs were protected by software copyright.

Another component in the computer aided design system that was not altered to service the needs of the architect was the workstation that included the vertical monitor. Licklider noted that the development of workstations, such as the swiveling cathode ray tube, did not get enough attention because the industry: "Didn't want to support the development of any software or computer systems that you wouldn't be able to buy from manufacturers after they were developed. And, therefore, the idea that people would build nonstandard hardware was very much looked down on."[727]

Without a true understanding of the computer's internal operations that could lead to possible design solutions, the human user becomes unable to completely manage the system. Originally, the main role of a computer's operating system was to help various applications interact with the computer hardware, but users' expectations of operating systems changed from

[725] Licklider. "Some Reflections on Early History."124.
[726] Michael D. Scott. *Scott on Information Technology Law* (Aspen Publishers, 2007), 18.
[727] Licklider. "Some Reflections on Early History."127.

the simple task of mediating between the computer's software and hardware, to assuming that the operating system would make it easy for the users to manage the system and its resources.[728] This expectation from the computer's operating system goes beyond the capabilities of the computer software.

From the programmer's point of view, the operating system obscures the details of the internal workings of the computer. These operating systems act as a layer between the computer software and hardware, creating a "friendlier environment" in which system resources are utilized effectively and efficiently and where programming in machine code is not needed. The operating system provides this interface to the human operator, but because it too is also an "ordinary piece of software," it is limited in its performance as a mediating agent by its own capabilities.[729]

With the development of personal computers in the 1980's, programmers developed new drawing programs that were modeled after already existing computer programs that had evolved from Sketchpad. And although the personal computers of the eighties were much smaller in size than the TX-2 computer that operated the Sketchpad system, both TX-2 and personal computers had the same amount of memory that was necessary to store pixel information for detailed graphic drawings.[730]

It has been argued that the incompatible partnership between the human being and the computer is due to the fact that the human brain gathers and actively structures information in a nonlinear way, whereas the computer gathers and structures information according to a linear and manufactured logic.[731] Sketchpad's program enabled the computer to work with the human user's information in the form of "geometric constraints." These geometric constraints included perpendicularity and proportionate dimensions. "Sketchpad's built-in satisfaction mechanism

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[728] Null and Lobur. *The Essentials of Computer Organization and Architecture, Fourth Edition*, 496.
[729] Ibid, 496.
[730] Henderson, *Encyclopedia of Computer Science and Technology*, 463. The TX-2 computer had 70,000 words of memory of 36 bits, which is the amount that was achieved by personal computers in the 1980's.
[731] Recently, scientists working in the field of neuroscience have become increasingly interested in exploring the human brain's interaction with art. This developing field that is related to artistic perception is a new field that has been called many names, such as *neuroaesthetics* and *neuroarthistory*. These scientists have made connections between this aspect of the human brain and the architect's brain, in the hopes that such connections may be beneficial to their research. Harry Francis Mallgrave, *The Architect's Brain: Neuroscience, Creativity, and Architecture* (Chichester, West Sussex, U.K.; Malden, MA: Wiley-Blackwell, 2010), 1.

worked to enforce constraints as the user fixed and changed properties of the graphics objects."[732]

Shannon warned against using the computer in tasks that were related to aesthetic judgment because he believed that the human-user would always be more superior to the computer in this field, and that by using the computer the designer was limiting his creativity to the capabilities of the computer program.[733] It was (and is) the nature of computer programs to eliminate many design possibilities and to dismiss design solutions that it thinks the human-user would not be interested in. Consequently, the human user selects a design solution based on the limitations of the computer program.

Mitchell believed that the computer-aided architectural design programs that were developed in the sixties and seventies reflected a narrow view of architectural discipline. According to Mitchell, architectural design had to be reduced to a limiting definition of problem solving, in order to integrate computer-aided architectural design programs into the creative architectural design process – consequently: "It is useful to regard architectural design as a special kind of problem-solving process, and to discuss design within the framework of a general theory of problem-solving… [Reducing architecture to problem-solving is necessary to create computer-aided design systems for architects]… This view is not without its limitations."[734]

By reducing architectural design as a problem-solving task, the distribution of design tasks between the human user and the computer became possible. With this new system for architectural production the roles of the two entities in the design process could be defined by determining which partner was more suitable to undertake a specific task.

Sutherland never claimed to have a vision for the future of computer science and the influence that Sketchpad may have had on the development of computer graphics. In 1989, when an interviewer asked Sutherland about the future of computer science, Sutherland replied: "This is the kind of question the answer to which requires hundreds of thousands of interviews. I don't have a window on computer science. I have a little tiny peephole that I look out at some corner

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732 Robert W. Lawler and Masoud Yazdani, *Artificial Intelligence and Education* (Norwood: Ablex Publishing, 1987), 173.
733 Shannon, *Claude Elwood Shannon: Collected Papers*, 691.
734 Mitchell, *Computer-Aided Architectural Design*, 27.

of the field that I'm interested in and have been able to keep track of."[735] In a paper that was published four years after the Sketchpad invention, Coons stated that:

> An important first step toward graphical communication between the designer and the computer was Ivan Sutherland's Sketchpad program. This program was completed in 1962. In computer technology, something that is four years old becomes very quickly worthless, including computers themselves. In this sense a four-year-old computer item is certainly an antique. From this point of view the original Sketchpad system appears almost as a remnant of the past.[736]

In an interview with Kay and van Dam: "Both lamented today's practitioners' lack of curiosity and historical context."[737] Although both admired Sutherland's Sketchpad invention, they believed that in order to push forward with development in the field of computer science, drastic change was required. As Kay stated: "We're incredibly wedged … conceptually, technically, emotionally, and psychologically into a tiny and boring form of computing that is not even utilitarian … I'd be happy to burn the whole thing down and start over."[738]

[735] Frenkel, "An Interview with Ivan Sutherland." 718
[736] Coons. "Computer-Aided Design." 8.
[737] Karen. "A Difficult, Unforgettable Idea." 21.
[738] Ibid, 21.

Conclusion

To conclude, I would argue that computer-aided architectural design programs inherited both the characteristics and the limitations of the Sketchpad system. Ivan Sutherland's Sketchpad is considered to be the first interactive computer-aided system developed according to the principles of the concept of human-computer symbiosis proposed by psychologist and computer scientist J. C. R. Licklider, in his influential and widely read article *Man-Computer Symbiosis.* As my dissertation has attempted to show, Licklider's educational background in engineering and psychology enabled him to view machines as living organisms that could have a symbiotic relationship with human beings if allowed.

Indeed, the drawing functions of Sketchpad were not the most innovative aspect of the system. This was rather to be found within the hitherto unseen "partnership" between human and machine. Computer-aided design systems originated from the need to establish an effective communication system between two dissimilar entities, the human and the machine, and with the introduction of Sketchpad both entities were able to cooperate in the design process by communicating with each other through the medium of drawing.

One of the founders of the computer-aided design group Steven Coons, who introduced Sketchpad to the architectural community, described Sketchpad as an "appropriate slave" that the architect would be able to make use of and would be able to communicate with through the computer's televisual window.

Sketchpad's drawing took place on the computer window, the same cathode-ray tube window invented for the television industry. As this dissertation has attempted to show, at the time of its inception literature and film had widely portrayed the machine as a threat to the future of human labor, often through the use of the female face and body. Assigning the female body or female face to technology made this threat identifiable, and as the dissertation reveals, Sketchpad's 'face' was the winking girl Nefertiti. Consequently, Sketchpad's Nefertiti simultaneously became both the architect's new partner in design, and a threat to his traditional role in architecture.

Licklider, Claude Shannon and Alan Turing viewed the computer as a living being that was inferior to adult human beings. As the dissertation showed, these computer scientists variously described the computer as an insect, an animal, a slave, or female child that the adult human had to teach and train. Furthermore, machines, robots and computers were developed to assist human beings by undertaking certain tasks that could be performed by repetition and by following a set sequence of steps but were provided by human drafters. Eventually, computers came to be viewed as almost like humans in that they could be relied on to replace human beings in certain aspects of design and drawing tasks. However, because Sketchpad was not invented to service architects, it left out fundamental aspects of architectural drawing that the new partner was unable to fulfill.

Interactive computer aided design systems emerged from the starting point of traditional drawing methods because the developers of Sketchpad did not want to create a drawing system that was too unfamiliar to potential users – mainly engineers and draftsmen – with the consequent risk of rejection from the beginning by these potential users. It was hoped that the transition from the traditional horizontal drafting table to the vertical computer window would be simplified if the new computer drawing resembled the descriptive drawing layout that draftsmen and engineers were already familiar with. However, like any viewer watching a scene on a television, the imposition of the hand had to be removed from the representation on the screen to clear the channel for the viewer watching the cathode ray tube window.

As the dissertation reveals, by replacing the architect's orientation to the drafting board from the horizontal drafting table to the vertical cathode ray tube window, and by gradually replacing the traditional pen with the light pen, and subsequently the mouse, the drafter became increasingly disengaged from the drawing and the architect was increasingly difficult to truly inhabit the architectural space of the drawing. The consequence of these changes was an increasing dependency on the computer to make design decisions, and an increased reliance upon the computer in the human-computer symbiosis in the process of architectural drawing.

Finally, Sketchpad's beautiful winking face made two new aspects of interactive, computer aided architecture design particularly clear. Firstly, it emphasized the notion of another entity collaborating with the architect in the design and drawing process. And secondly, it showed that this new 'partner' would not just begin to take on but master and replace vital elements of the design decision-making process. Consequently, the beautiful, winking face needed to be approached with great caution.

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