Plugged-in: 40 years of digital imaging

Carol Christy Brown

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ROCHESTER INSTITUTE OF TECHNOLOGY

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In Candidacy for the Degree of
MASTER OF FINE ARTS

Plugged-In : 40 Years of Digital Imaging

by

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Composed by Randy Newman
Produced by Lenny Waronker
TRISTAR Pictures/
Warner Brothers, 1984

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A thermographic of people in motion by Richard Lowenberg from the book
“Computer Images” by Joseph Deken

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Statement of the Problem

It was my intention when I chose this project to provide not only for others, but also for myself, some kind of overall understanding of how the digital imaging field came about and where it was going. Up until now there have been very few books written on the subject that I felt were comprehensive enough to get the full impact of how computer imaging was changing the face of art forever. When it came time to decide on my thesis project, it was very clear to me from the start. I wanted to create an educational interactive piece that would address this subject in the fullest way possible given the time I had to do it in. Ultimately I wanted the user to be able to explore history in the making and gain a sense of this monumental effort, the speed in which it developed, and its endless possibilities. It took me many months of research and a great many phone calls to artists whom I might add were extremely generous with their time considering their very busy schedules.
Objective

To create an interactive piece that will provide to the user a feel for the rapid development of digital imaging, the key players involved and its impact on the way we create visual media today. This interactive presentation will seek to establish how this new medium emerged from the collaboration of many creative minds in the scientific and art worlds. The field of digital imaging should be of interest to many because of its inevitable impact on the way we live. Forty years of historical development from 1950-1990 will be presented, spotlighting pioneers and artists involved in the development and use of these tools. This project will be useful as an adjunct to any educational program either in the area of digital imaging or other areas seeking information about the digital arts. I hope that those that view this project will come away with a more enlightened understanding of this truly exciting and dynamic field.
Introduction to Digital Imaging

Though still in its infancy, digital imaging is already revolutionizing the way art and design are conceived, created and perceived. Not long ago the introduction of quick-drying acrylic paints was hailed as a major breakthrough. Today another medium allows us to expand our aesthetic possibilities - the computer. Electronically, a composition can be recolored in seconds with a choice of millions of colors, and the interplay between light and shadow can be completely transformed with the touch of a cursor. Two-dimensional and three-dimensional images can be created with life like accuracy. Animation, movies, audio, and photographs can be manipulated and/or combined with a variety of techniques. No wonder artists as diverse as David Hockney, Kenneth Noland, Philip Pearlstein and Robert Rauschenberg, have all embraced this new technology.

The term "computer graphics" will be used throughout this document in reference to "digital imaging." The latter term became more widely used in the late eighties to describe and include an ever increasing variety of images created on the computer today.
Review of Related Literature

1950-1970

Thirty years ago William A. Fetter, a research scientist with Boeing Company in Renton, Washington coined the term “Computer Graphics”. This term became a catchall term for anything graphic created on the computer. Within the same period some mathematicians and artists presented their graphic creations to the public. These images were generated with the aid of the recently introduced computer graphics systems which had originally been devised for the creation of maps, charts and mathematical diagrams. Even before the first pioneering exhibitions took place in 1965, experiments had been conducted with these initial graphic computing systems with the sole purpose of aesthetic expression in mind. ¹

The first known work of this type was by Ben F. Loposky, a mathematician and artist from Cherokee, Iowa. His “Oscillon” series created in 1950 were considered the first graphic images generated by an analog computer. These oscillons were composed of photographs of electronic wave forms displayed on a cathode-ray tube (CRT). For many years, they represented the most advanced achievements of what was known as computer art. ²

In the decade following Laposky’s first oscillon, there were important technological breakthroughs that suggested wider visual possibilities, but the use of the computer for imagemaking remained primarily a scientific pursuit. This decade laid the technological groundwork for the vast experimentation with computer art that took place during the 60’s and that continued to escalate during the 70’s and 80’s. The four major advances were: a computer called “The

¹ Franke and Siemens AG, p.1
² Goodman, Visions, p. 19
Whirlwind", the “CRT” or “monitor” for display, the “plotter” for graphic output on paper, and the “scanner”, a tool by which a photograph or image can be digitally stored in the computer’s memory and later reproduced.3

In 1950, the same year that Laposky’s oscillons were introduced, the “Whirlwind I” computer became the first to make the connection between the computer and the CRT. This early graphics computer was created by engineers at MIT and could display mathematical data in visual form and animate it. 4

Shortly after the “Whirlwind” made its debut, a method for feeding pictures into a computer by scanning them on a rotating drum was first used on the U.S. Standards Automation computer system. According to Russel A. Kirsch of the National Bureau of Standards, this picture-processing technique was revolutionary because it was the “first time that a computer could see the visual world as well as process it.” The first image-processed picture was of Kirsch’s baby son. 5

The CRT vector displays created during this time period, produce images composed primarily of lines. Raster-scan CRT’s which are much like the ordinary television tube, emerged later as the dominant display technology for computer graphics. These devices would later permit greater flexibility with color, the ability to selectively modify arbitrary areas of the display down to a single pixel, and the capacity to render objects with smooth shading and realism. Most computer images today are produced on this type of device.6

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3 Goodman, Visions, pp. 18-20
4 Scott, p. xii
5 Goodman, Visions, p. 20
6 Goodman, Visions, pp. 62-63
One of the first systems employing vector display technology, initially designed at the University of Utah in the ‘60’s, allowed the computer or user to dynamically modify the image description data while the display device is updating the screen. This creates the effect of real-time animation, an important advantage for interactive graphics systems. However, the computing power, memory, and speed required to refresh a complex image at this time were often prohibitive.  

Devices analogous to the vector CRT were developed for producing plots on paper. These hardcopy devices move a pen across the paper, providing the added color capability not available in the early vector CRT’s. One of the greatest technological advancements for both artists and scientists, during this period, was the creation of a “sketchpad system” by Ivan Sutherland at MIT in 1962. With the Sketchpad, the user could draw directly on the screen with a light pen. The images were created by the demarcation of a path of light which could then be digitally stored and retrieved later.  

With the flourish of technological advancements being made in the creation and display of computer graphics during the 60’s, it was only a matter of time before the art community began to take notice. In 1963, the trade periodical Computers and Animation announced the first competition for computer graphics in which winners were to be chosen on the basis of aesthetic merit instead of design practicality. Although the images chosen were significant more for their mathematical ingenuity than for their artistic achievement, the lofty recognition that art could be made with a computer was attained.

7 Scott, p. xii  
8 Goodman, Visions, pp. 21-25  
9 Goodman, Visions, p. 22
The same year as the first computer graphics competition in 1963, the first computer generated film was produced by Edward E. Zajac at Bell laboratories. He used the same equipment on which Leon Harmon and Kenneth Knowlton two years later were to create their famous nude. ¹⁰

Knowlton was among a group of pioneers who saw the advantages that the computer had to offer over conventional filmmaking. In 1964, He created the BEFLIX computer animation language—the first of its kind at the Bell Labs where he produced a dozen computer films between 1963 and 1967.¹¹

In 1965, the idea of computer art began to receive general public attention both in the United States and Europe. Three mathematicians, Frieder Nake, A. Michael Noll, and George Nees, arranged the first exhibition of computer generated art at the Technische Hochschule in Stuttgart, West Germany. That same year, the first exhibition of digital graphics in the United States was shown at the Howard Wise Gallery in New York, a gallery well known for its receptivity to and encouragement of technologically advanced art. On display were photographic enlargements of microfilm plotter output conceived by Noll and Bela Julesz. Both of these scientists worked at Bell Telephone Laboratories in Murray Hill, New Jersey - a leading center for computer graphics, computer animation, and electronic music research and development since the early 60’s. That the exhibitors at the Wise Gallery were scientists and not artists was as revolutionary at the time as the fact that their works were drawn by a plotter instead of by hand.¹²

There were obvious limitations to the graphics systems used at this time. Creation and output were restricted to black

¹⁰ Reichardt, p. 79
¹¹ Jankel & Morton, pp. 21 - 25
¹² Reichardt, pp. 23 - 27
and white, color devices had yet to make their entry into computer graphics. In spite of the technical limitations and lack of artistic pretension - the Wise Gallery exhibition successfully demonstrated the capability of computers to generate intriguing visual displays.13

In one playful experiment, Noll produced a convincing facsimile of Bridget Riley’s painting Current from the collection of New York’s Museum of Modern Art. He expressed the top line of this Op Art composition as a mathematical sine curve and then instructed the computer to repeat it several times. His successful representation of the original led him to investigate whether the computer would do equally well with different forms of abstract painting.14

In another experiment, Noll produced a semirandom picture remarkably similar in composition to a 1917 Mondrian, called Computer Composition with Lines. He then presented photocopies of the original Mondrian and the computer generated picture to one hundred people at Bell Labs. The subjects, who were informed that they were about to participate in an exploratory experiment to determine what aesthetic features are involved in abstract art, were instructed to identify the computer picture and the picture of their preference. Only 28 percent correctly identified the computer-generated picture, while an astonishing 59 percent preferred the computer’s rendition to the actual painting by Mondrian. According to Noll’s provocative conclusion, the people in this survey “seemed to associate the randomness of the computer generated picture with human creativity, whereas the orderly bar placement of the Mondrian painting seemed to them machinelike.” 15

13 Goodman, Visions, pp. 25 - 27
14 Goodman, Visions, pp. 25 - 27
15 Goodman, Visions, pp. 25 - 26
Review of Related Literature

A programmer and engineer, Noll continued to research and write on a wide range of computer and art-related topics, making a major contribution to the development of computer graphics. At an early stage, he foresaw that the computer would have ramifications well beyond the creation of two-dimensional imagery. He pioneered three-dimensional movies (seen in stereoscopic views) and wrote programs for computer-generated choreography and holography.\(^{16}\)

In the mid-1960's, artists began to develop interest in computer graphics, thus extending its applications. One of the few people involved in computer graphics with a traditional art background was Charles Csuri, an artist on the Ohio State University faculty. Csuri is credited with producing the first examples of computer-generated representational art. In contrast to Noll's mathematically generated, abstract computer imagery, Csuri's compositions originated as pencil drawings of representational subject matter. The images were scanned and converted into digital information. Coordinates were then assigned to the outlines, and the compositions plotted either in their original form or completely transformed, according to the program Csuri desired.\(^{17}\)

In the same year, Robert Rauschenberg and Billy Kluver coproduced a collaborative computer art performance series that lasted for nine evenings at New York's 69th Regiment Armory - the site of the revolutionary show that introduced modern art to America in 1913. Rauschenberg and Kluver called on forty engineers and ten well-known avant-garde artists to produce the technical equipment for the theater, dance and musical extravaganzas to be performed. Although the audience became disgruntled by the shows' long delays and frequent breakdowns and the press generally panned the events, there were many technical successes and stunning visual effects.\(^{18}\)

16 Reichardt, p. 25
17 Reichardt, pp. 34 - 46
18 Schwartz, p. 7-12
Stimulated by their conviction that interdisciplinary action would benefit not only the participants but also society as a whole, Kluver and Rauschenberg formed an organization called Experiments in Art and Technology (E.A.T.) with the objective of promoting joint efforts between artists and engineers. The opening meeting in Rauschenberg’s studio in 1967 received considerable coverage in the press.19

One of the many artist pioneers in computer graphics influenced by E.A.T. was Lillian Schwartz. In 1968, John Vollaro, a technical staff member under Leon Harmon at Bell Labs, began to teach Schwartz how to use the computer. He patiently explained the underlying concepts, the hows and whys of bits, transistors, processing units, and cathode ray tubes. While he spoke of these things, she recalls, “I was mesmerized by the dots of light I could create on the monitor. Turning the lights on and off reminded me of Times Square late at night, when the neon signs flickered with such intensity that my eyes would rapidly tire, casting an unfocused halo around the colors.” “I dreamed of only using the machine”. Lillian Schwartz would be faithful to the machine for many years, creating a multitude of artwork, conducting a myriad of experiments and writing a book on the techniques of computer graphics.20

In that same year, the largest computer graphics exhibition ever produced was organized by Jasia Reichardt of the Institute of Contemporary Arts in London. The exhibit was appropriately called “Cybernetic Serendipity.” Max Bense suggested to Reichardt that a work of art will be understood here as being any aesthetic formation which has arisen on the basis of the logical or numerical transposition of given data with the aid of electronic mechanisms.21

18 Schwartz, pp. 7 - 12
19 Schwartz, p. 5
20 Reichardt, p. 5
Charles Csuri began producing films almost as soon as he started creating computer art. By 1970, Csuri had successfully developed a real-time film animation program on an IBM 1130 system. Once a user called up an image on the display terminal with a light pen, the computer could be instructed either to put the object into motion or to change its shape and size. Csuri had designed the system with artistic applications in mind, and he considered his installation to be an interactive artwork. Indeed, it was the precursor to interactive design media which we use to create multimedia presentations today.  

One of the experimental drawing systems of the early 70’s was created by the British painter Harold Cohen. He left a successful career as a traditional artist to devote himself to a minicomputer he had inherited. Cohen had devised a computerized system to compose and generate line drawings, later adding color by hand on the printed copy. He wrote a novel-length program called AARON, that applies artificial intelligence techniques to the process of image making.”

The “paint system” developed in 1975 was by far the most popular way to generate two-dimensional computer graphics. These systems allowed the artist to operate within a traditional framework. With a typical configuration of hardware and software, the artist draws on a digitizing tablet using a light sensitive pen and chooses from a palette of colors and a selection of brushes which are displayed on the monitor.

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22 Goodman, *Visions*, pp. 158 - 159  
23 Schwartz, p. 250 - 251
Credit for the development of the configuration of virtually all paint systems goes to two men: Richard Shoup, founder of Aurora Systems, and Alvy Ray Smith, vice president of Pixar. Shoup is credited with originating the idea for an interactive animation system and for developing the Xerox Palo Alto Research Center in 1973. Smith, who had worked with Shoup, transferred in 1975 to the New York Institute of Technology Computer Graphics Laboratory in Westbury, Long Island. At NYIT, he produced PAINT, the prototype for most paint systems on the market today.24

Artists as diverse in their styles as Andy Warhol, David Hockney, Kenneth Noland, Jennifer Bartlett, and Philip Pearlstein have experimented with electronic paint. For Warhol, the appeal was the resemblance of computer-generated images to his own work: “The thing I like most about doing this kind of work on the Amiga is that it looks like my work in other media.” Once Pearlstein overcame his initial resistance, he was, like Warhol, amazed by the ability of an electronic palette to create effects of impressive subtlety in a stylistic range comparable to that of his customary materials. Hockney was intrigued by what he called “painting in light,” an effect he believed to be equaled only in stained glass. Painter Kenneth Noland is among the converts to digital imaging tools, and he has totally immersed himself in the new medium through his involvement with computer-processed video. He has built a professional-quality recording and editing facility adjacent to the studio where he continues to paint in acrylic on canvas.25

Barbara Nessim, like Noland, uses the computer to create drawings similar to her work in conventional media. The point of departure for both are sketches in the three or four

24 Goodman, Visions, p. 62
25 Binkley, pp. 228 - 240
Review of Related Literature

Barbara Nessim
Communications Disc

diaries she completes each year. Once her computer drawings are printed, she delicately colors them by hand with pastel. Nessim’s work often examines the relationships of men and women, and her drawings are charged with an eroticism and sexual energy evoked as much by the frenetic quality of her lines as by subject matter - a feeling conveyed even more effectively by the heightened video palette of the computer.26

Interactive paint systems have become the predominant medium of many artists. Darcy Gerbarg, one of the most active members of the computer art community, began searching in 1978 for a medium capable of achieving modern pictorial effects analogous to those produced by the audio-synthesizer in electronic music. The following year she learned about the user-friendly interactive paint system developed at NYIT. She spent the next eighteen months working on this system.27

Gerbarg was ecstatic about the versatility of the paint systems, but, she was disillusioned by the lack of quality output. She commented, “In each case, going from a non-physical medium has required substantial experimentation and a solid knowledge of colored pigments and the chosen medium as well as the properties of colored light. Ultimately I would like to “paint” images digitally, feed this digital information directly to a hardcopy device and “print out” any scale finished work in a permanent medium with surface and color qualities that rival oil or acrylic paint. The technology to satisfy my imagination exists for the creation stage in colored light only. The technology to realize the physical artwork directly from digital information in full-color lags behind.”28

26 Goodman, Art Journal, pp. 248 - 252
27 Goodman, Visions, p. 64
28 Skidmore College, p. 6
Artists like Gerbarg, Nessim and Pearlstein have used digital paint systems in the most traditional manner possible. For them the computer is a direct extension and amplification of their work in other mediams. Other artists manipulate and enhance images electronically through image processing. These techniques manipulate digitized images stored in the computer's memory and can be used in conjunction with paint systems to produce what we call today "special effects."\textsuperscript{29}

Howard Hodgkin, Sir Sydney Nolan, Peter Max, Keith Haring, Larry Rivers, Mark Linquist and Jack Youngerman are also among some of the of well-known artists who have worked with digital paint systems. For these artists, image processing offered an otherwise unobtainable visual vocabulary. Today, photographs and video images of live action can be scanned and manipulated with a variety of software programs. They can then colorize, add varying degrees of transparency, change the size of the pixels, create three dimensional effects, add realistic textures with a method called bump mapping, and even include movement and sound.\textsuperscript{30}

The most extensive research in three-dimensional modeling took place in the mid to late 70's at seemingly unartistic places like IBM's Thomas J. Watson Research Center, Los Alamos National Laboratory in New Mexico, Lawrence Livermore Laboratory in Livermore, California, and the Jet Propulsion Laboratory of the California Institute of Technology. The algorithms of computer researchers Richard Voss, James Blinn, and Nelson Max set the standards for the commercial, scientific, and artistic fields.\textsuperscript{31}

\textsuperscript{29} Goodman, \textit{Visions}, p. 72
\textsuperscript{30} Goodman, \textit{Art Journal}, pp. 248 - 252
\textsuperscript{31} Goodman, \textit{Visions}, p. 107 - 108
In 1976, James Blinn defined a set of algorithms for bump mapping, creating the illusion of texture on the surface of a three dimensional object. The artistic applications of Blinn’s programs have been developed most successfully by David Em, who holds a position as Artist in Residence at the Jet Propulsion Laboratory. Em has access to powerful computers and to software developed by Blinn. The space age look of his otherworldly images may be attributed to the fact that the programs he uses were not developed for art purposes but for scientific research, primarily for NASA. His data bases contain outer space phenomena transmitted back to earth from Saturn or the Jovian moon.32

Fractals were welcomed enthusiastically by a computer graphics world anxious for more convincing abilities to depict landscape. Richard Voss, of IBM, has done extensive research on the application of fractals to computer graphics imagery. He has produced some breathtakingly beautiful constructions of mountainous terrains and cloud-filled skies. The geometry of fractals, with seemingly magical capacity to recreate our world as a mathematical construction, has caught the imagination of artists as has no other modeling technique.33

During this period, Melvin Prueitt, like David Em, utilized the mathematical capabilities of the computer to create intriguing surrealistic landscapes. Prueitt was a physicist at the Los Alamos National Laboratory. He left weapons design to devote full time to the development of advanced computer graphics. Prueitt creates whimsical visions of brightly striated, spiky terrains with the aid of one of our most powerful computers, the “Cray”. 34

32 Em, pp. 11 - 13
33 Goodman, Visions, p. 114
34 Goodman, Visions, p. 115
1980-1990

The 80's brought on a flurry of work being produced in the field of computer graphics. All types of artwork were explored by many kinds of artists from graphic designers to those schooled in the fine arts. Much of this activity can be attributed to the availability of computing power and software brought on by the release of the IBM PC and the Macintosh, the so called "personal computers." Computer Graphics was no longer only available to those that had access to the great computing laboratories of science and academia, but could be purchased at an affordable price and used within the home, studio or office.

One of the techniques made available in the 80's that was most successful in defining light, and therefore most successful in the depiction of convincingly realistic scenes, is called "ray tracing." The first work on ray tracing was that of nuclear physicist Philip Mittelman at MAGI in the late 1960's. However, Turner Whitted is credited for developing ray tracing and introducing it to the computer graphics community in 1980. The pictorial marvel of ray tracing is that it not only takes into account hidden surfaces, highlights, shadows, but also copes magnificently with reflections, refractions, transparency, and textures. Both ray tracing and fractal geometry made it possible for certain very sophisticated software packages to be available to artists with desktop computers today.

The SIGGRAPH Art Show made its debut in 1981. Many of the technological advances in film animation and 3D rendering over the last twenty years were seen by artists for the first time. Turner Whitted's Spheres was chosen as the

35 Goodman, Visions, p. 17
theme image for the convention. This image was not only visually appealing, but also demonstrated the most recent and elegant method of lighting curved and reflected objects by ray tracing. Each year artists and animators work around the clock to have their work completed in time for this annual exhibition.36

Another sensation at SIGGRAPH ‘81 was Carla’s Island, a four and one-half minute movie depicting an aerial view of an island throughout the course of a day, from sunrise to sunset to moonlit nighttime. The scenes were created on a Cray I supercomputer using ray tracing techniques developed by Max. It represented the most sophisticated application of animated computer graphics and ray tracing techniques at that time.37

Throughout the 80’s, many filmmakers using a combination of the newly available 3D modeling and animation techniques, made their debut. One of the foremost computer graphics artists/animators in the world is Japanese artist Yoichiro Kawaguchi. He is one of a new breed of artists specifically schooled in computer graphics filmmaking as an art form. His breathtaking simulations of underwater life are influenced by diving trips in the East China Sea. Yet unlike most computer animators, who strive to attain approximations of reality, Kawaguchi seeks “realistic” depictions of his fantasies.38

Some of the most acclaimed computer generated movie sequences have been created by the Computer Graphics Project Division of Lucasfilms, Ltd., in collaboration with Industrial Light and Magic, the Special Effects Division of Lucasfilms. They include “Star Trek II” and “Return of the Jedi.” Another film well known for its exploratory computer animation sequences is Disney’s “Tron”.39

36 Jenkal & Morton, p.48
37 Goodman, Visions, p.164
38 Kawaguchi
The simulation of reality is a challenge of unabating interest to the computer graphics world. Researchers continue relentlessly to refine and improve. They seek to illuminate more accurately, to shade more smoothly, to shadow more realistically, and to simulate landscaped scenes, some populated with three dimensionally modeled objects or living creatures of such detail and complexity that they appear photographic in their reality.  

In 1986, computer graphics technology made a different kind of news because of a comparison study done by Lillian Schwartz with the Mona Lisa and Leonardo da Vinci’s self portrait. Gerard Holzmann asked Lillian Schwartz if she would test his PICO program by putting it through some operations. She decided to scan a photograph of the Mona Lisa and a drawing of Leonardo. Schwartz chose to compare them because she began to see the features in the Mona Lisa as being more masculine than feminine. The two images were placed on the screen; half of one and the mirror half of the other to compare facial features. The alignments of the eyebrows, eyes, nose, etc. matched up almost too perfectly. Once it was obvious that the matchup was atypically perfect, her initial conclusion was that Leonardo had used himself as the model for the finished Mona Lisa. She went through a series of composites on the computer to see if she could dislodge the calculations. Everything she did served to confirm the original finding. The analysis resulted not only in an exhilarating discovery but also a database of images with which she was compelled to experiment. She went through a period of addiction to her variations on Mona. Although Schwartz spent years experimenting and pushing the computer medium to represent the images she created in paint, she is probably best known for her Mona Lisa experiments.  

39 Goodman, Visions, p.179  
40 Schwartz, pp. 270 - 276
In the late 70's and throughout the 80's, some designers and illustrators began to explore the capabilities of the computer. Some of these artists such as April Greiman, Wendy Richmond, AAaron Marcus and Mathew Carter have become pioneers in their field of interest for their experimentation with the fusion of technology and traditional methods.

Because of these dedicated men and woman, today we have a myriad of capabilities on our desktop. Some of the most commonly used software in the creation of computer graphics are: Adobe Photoshop for manipulating photographic images and combining them with design and type, Ray Dream Designer for ray tracing and texture mapping, Painter to achieve painterly effects, Adobe Premiere for movie making, Macromind Director for animation sequences, and Adobe Illustrator and Aldus Freehand for illustration and design. Of course there are many other products that could be mentioned, and many more that have yet to be created. Artists with an understanding of computer graphics can use these software products alone or in conjunction with each other to produce astounding visual affects.

Although the technology is here to produce endless possibilities of creative imagery, they are still working on the output of these images. So far, the output devices available that come realistically close to reproducing the image that we see on the monitor, are far too expensive for an individual to own and producing this output at a service is somewhat costly. Many artists are still using the computer in conjunction with traditional techniques to produce final results of their creative expression.
Research

Research was divided into two phases. The first phase was to research the history of digital imaging over the last forty years, and compile the information into a paper and bibliography. This phase was initially important in finding out who the key players were in the development of imaging software and hardware, and the artists using digital imaging over the years. During the early years it was often hard to separate the artists from the scientists because many times they were one and the same. As I did this research it became clear to me that there were some natural time period breaks forming within this forty year period. The first was (1950-1970), a twenty year period of initial discovery. This period was distinguished by experimentation and a slow moving exploration of crude imaging techniques done primarily by scientists. These early scientists were connected to major laboratories around the world and had access to large main frames and later supercomputers used in the space program. The second time period (1970-1980) was the marriage of artist and scientist. Many famous and not so famous artists got involved at these labs working together with pioneering scientists. The two together created an important link in the development of imaging software. The artist offered invaluable information regarding the needs of the artist; the types of tools necessary to do a job and the user interface information. These artists were the first testers of these early products. The third time period (1980-1990) involves the explosion of software and hardware primarily because of the advent of the microcomputer. Artists everywhere began to have access to this fascinating new tool. As the products
became more prevalent, pricing came down making it even more accessible. Along with this micro explosion came an explosion of images.

The second phase of my thesis research was primarily focused on pinpointing those pioneers that made the most important contributions, also well known artists in a variety of fields today using the computer for their primary imaging tool. At this point I created an initial outline or plan for the overall project. See Appendix (A). I also needed to compile the primary events that lead up to the nineties in digital imaging development. Additional research was undertaken to gather more information on these individuals and events. Often this necessitated me calling the artist or scientist directly to obtain biographies, interviews in print or on tape and images. I was able to acquire timelines from many sources (see Bibliography) for dates of important historical events in digital imaging. These I merged and retrieved the most important of events for my thesis. See Appendix (B).
Design and Specifications

After most of the research was done, I could then begin a somewhat realistic attempt at a working schedule for the creation of the interactive piece from beginning to end. See Appendix (D). Also at this point, I felt that I could put down on paper the initial design of how the interactive piece should take shape. See Appendix (C) for layout of the completed design.

Design:

I knew at the beginning I wanted some form of movie intro that would show a quick synopsis of what digital imaging is about and what this project will attempt to provide. This was attained by creating a logo of a computer in the sky anchored by a red electrical line running from one side to the other, through the computer and plugged in at the other side. Photos of artists, scientists, and images would then flash to the beat of a music/voice over introduction. The movie would then fade to the Main Menu.

The Main Menu would give the user four choices; An Introduction, A Visual History, Pioneers Speak, and The Electronic Studio. See Appendix (E) for menu design and screen layouts. The Introduction is a written version of the voice over introduction. When choosing A Visual History, the user is prompted through two other menu choices; Image Archive or A Visual History. After choosing one of these, three time periods which comprise forty years of imaging appear as choices. A Visual History allows the user to view
major historical events in the development of digital imaging
or go to an Image Archive in one of the three time periods.
Pioneers Speak allows the user to view one of three pioneers
that helped to shape the course of digital imaging. In The
Electronic Studio section, the user can choose one of five
artists using computers to produce their work today. Each
artist is a well known representative of either graphic design,
illustration, animation, photography or special effects in
film.

User Considerations:

One of the primary user considerations was to make it as easy
to navigate through the project as possible since it was fairly
large. Help, and a stack map were provided for "how to"
information and ease of movement. Help would provide
"local" information having to do with "how to use buttons,"
etc. on the screen which was presently available. The stack
map would give an overall or "global" picture of the project,
tell users where they are presently and allow them to go
somewhere else in the project or return.

On each menu, in the upper left hand corner is a button for
voice information about that menu and an introduction to
the menu's content. I felt that this was a very important
component of the project so that the user always knows what
each area has to offer content-wise. Also, it was not activated
automatically so that the user did not have to listen to the
intro each time he/she came to that particular menu.
There were four varieties of buttons in the project to make them easy for the user to recognize. The first set were on every menu and allowed the user to do things common to the entire project. These were Quit, Bibliography, Help, Stack Map, Main Menu, and Credits. These were small in size but always remained in the same position, like an anchor in the project. The second set were the buttons for navigating menu selections. On the first few menus, the buttons were part of a control panel design. On the other menus having to do with specific artists and pioneers, I chose to use close up photo images of them as buttons to navigate their areas. The third kind of buttons were within the archives and historical sections. These buttons would help the user navigate through the archive of images, toggle between quotes and bios, descriptions and data, print the screen or find a card based on word input. This group was always along the bottom of the viewing area for ease of use. The last set of buttons were created for viewing video images. These used the standard buttons seen on VCR's. I tried to make all buttons in a consistent manner so the user could easily identify them. All buttons had special sound effects when clicked to help identify them.

**Software and Hardware Used:**

When certain design decisions were established, I then had to choose the software and hardware to be used. See Appendix (F). I knew that this project would require a fair amount of memory so I immediately investigated upgrading my ROM from 16 MBs to 24 MBs. The last thing I wanted to happen was to have serious memory problems degrading my development and testing time when I was trying to meet a deadline.
The other memory consideration was backup. I wanted to be able to backup my hard drive and have some memory left over for this project. I investigated optical and external hard drives and decided on a 270 MBs external hard drive. This decision was primarily made because it fit into my budget and it would do the job.

For software, I decided to use Aldus SuperCard for the main interactive software. This decision was made primarily because I already had a large amount of data for this project in SuperCard and because of time constraints. I did not want to rewrite the field information in another product. SuperCard proved to handle the amount of information adequately. However, it became slow as the project grew, dissolves looked choppy, and it was impossible when it came to dealing with type. Every font type, color, justification, etc. of every field on every card had to be changed individually or within a loop. While trying to figure this out, there was little or no support because the product was no longer supported by the company and very few people knew it. So in retrospect I do not know if SuperCard was the best choice and wish I had had more time to investigate other products.

For the title animation, I decided to use MacroMedia Director. Director handles animation very well and this proved to be a good choice overall. The only problem which arose was getting sound and music timing together. When creating the movie within Director, I had no problem with this, but when the movie was opened within Supercard to play, both movie timing and sound timing shifted substantially.
Video brought its own set of problems to be resolved. All movies were captured using Video Spigot software and the lab’s Quadra 800 with video board. Initially I had problems with sound. The recorded sound had a lot of external noise and it was very bad quality. With the help of a colleague, we discovered that the microphone input jack on the computer had been corrupted so we needed to figure out a way to bypass this problem. We did this by loading the MacRecorder software and using the MacRecorder hardware as a go between, plugging it into the sound jack and video output source. Sound was improved dramatically.

The next difficulty was with the video quality. A lot of fine tuning had to be made, both on the video deck and within Video Spigot software, for sharpness, hue and saturation. The next decision to be made was the size of my videos and compression. I chose to compromise on both, choosing a format of 160 X 120 pixels and medium compression. This was to save some space without compromising too much quality and worked quite well.

Distortion also occurred when the video clips were brought into the viewing area within the project. I resolved this problem by creating a grey rectangle exactly the size of the video clip in Photoshop for the clip to superimpose. When the clip was opened to play, it fit to this rectangle perfectly so there was no distortion at all.

Another problem I had was with the software Disk Doubler. This software temporarily compresses files not being used so as to save hard disk space. This caused a problem if the video
clips were disk doubled when brought into SuperCard. The user would have to wait up to thirty seconds while the video was being decompressed in order to view them. This, I felt was unacceptable so I turned off disk doubler on my system and used the uncompressed versions.

Video had some special requirements in SuperCard in order to play. First, QTMovie had to be brought into the SuperCard project as a resource and certain scripts had to be either on the button or card level, and also on the project level. To bring QTMovie in as a resource, I had to either find a SuperCard Stack that had it already, and cut and paste it into the resource fork of my project or convert a HyperCard stack that has QTMovie to a SuperCard Stack, and do the same. Furthermore, full path names must be specified for SuperCard to find the movie and to play a Director movie, MacroMind Player must reside in the same folder or on the same level as the SuperCard Project.

Hewlett Packard proprietary software “DeskScan II” was used to scan over two hundred images. Each image was scanned slightly larger than the appropriate size at 72 DPI. These images were then taken into Adobe Photoshop to be sized down, color adjusted etc. The backgrounds of each menu were also created in Photoshop. Richard Lowenberg’s thermographic of people in motion was made into a greyscale image and then filled with color. A couple of passes with different shades of purple and lavender gave a nice, mysterious, electronic image to represent this historical project. A grey mottled control panel was then layered over the top suspended in air like the magic it represents. The
grey texture was created in KPT Photoshop Tools. The second type of menu has photo closeups of each artist or pioneer suspended over the same background. Each image was outlined with the same color grey from the panel. The image navigational buttons were also produced in Photoshop and have a metallic grey rock appearance to go with the grey and lavender color scheme of the menus, providing visual continuity. All menus had some common areas. These areas had to be carefully copied into each menu so that no shifting would occur when flipping from one menu to another, so it appeared seamless.

Within the Archives, I chose to leave the navigational areas with no textured background because I did not want to interfere with the viewing of artwork. Even neutral shades, I found had adverse effects in some situations. Because of the large variety of images in the archives, I decided to leave the backgrounds white like gallery walls and unfettered by textures.

Within the Historical section, I chose a historical image of that period to be the background. This image was greyscale at fifty percent saturation- a ghost like image. At sometime in that time period the background image would be an event that was explained.

Originally, I used scrolling fields for descriptions, however, I felt the descriptions were too large and difficult to see. The scrolling fields also turned white within the field when scrolled which created an aesthetic problem. Each description was therefore made more concise so it did not
need a scrolling filed and another patch of white at twenty five percent was placed behind the writing to make it easier to read.

For the voice work, my friend David Sholty, a voice-over professional from Chicago, used Sound Edit Pro to record the segments. He then created these files after I sent the script to him via American On Line. See Appendix (G). The sound files were then sent to me on diskettes. All files were compressed with Stuffit Deluxe. We chose to mail the sound files by Federal Express instead of sending them via the modem because after calculating the time it would take to transfer them based on their size and the speed of the modem (2400 baud), we decided it would not be cost effective. Sending them this way would be much more expensive, not mentioning tieing up the phone lines and computer for that period of time. When I received the files, I separated each menu intro in Sound Edit Pro and saved them as separate resources in a HyperCard stack. A problem resulted when I tried to create a SuperCard stack from the Hypercard stack. SuperCard recognized these file as one file and would not allow them to be imported to my project. So, using an older version of the software called “Sound Edit”, following the same procedure, I was able to finally create a HyperCard stack which saved the resources as separate files in a resource fork. At this point I could convert to a SuperCard stack and cut and paste the sound resources into my project.
Requirements to Run Project:

- SuperCard 1.6 or greater
- Macromind Player of Macromedia Director 3.1.1
- System 7.1
- Quicktime™ extension
- Macintosh FX or greater with 16MBs + of RAM and a Hard Drive with at least 90 MBs available for storage of the entire project with movies.
- Color monitor set at "Thousands of Colors" - this negates the possibility of a white flash which can occur when the Intro movie finishes, leaving Macromind Player and goes to SuperCard to display the Main Menu.
- The project for "Plugged-In" - presently called "CG History.large" (the name of the project may change).

- All movies:

<table>
<thead>
<tr>
<th>Movie</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ThesisBegTest2</td>
<td>The animated Director movie to introduce “Plugged-In”</td>
</tr>
<tr>
<td>1984-60 sec.</td>
<td>The Apple 1984 commercial introducing the Macintosh</td>
</tr>
<tr>
<td>Johna</td>
<td>John Lasseter interview 1</td>
</tr>
<tr>
<td>Johnb</td>
<td>John Lasseter interview 2</td>
</tr>
<tr>
<td>Johnc</td>
<td>John Lasseter interview 3</td>
</tr>
<tr>
<td>TinToy2</td>
<td>segment of John Lasseter’s animation</td>
</tr>
<tr>
<td>Luxo Jr</td>
<td>segment of John Lasseter’s animation</td>
</tr>
<tr>
<td>KnickKnack</td>
<td>segment of John Lasseter’s animation</td>
</tr>
</tbody>
</table>

* If the hard drive is changed, the pathname of the movie needs to be changed in the script of the movie button that plays that particular movie. For example, "Christy HD: Movies:KnickKnack".

- Fonts needed:

  Futura Condensed
  ITC Stone Serif
  Helvetica Condensed
  Times
The process in developing this thesis allowed me to experience solving some sticky problems involving hardware and software. This is the area I get most frustrated with especially when it involves some understanding of the engineering side of things. However, with perseverance I conquered the machine and with experience comes confidence. I especially enjoyed the research because I got answers to questions about digital imaging that I have carried with me for a long time. Contacting some of the leading pioneers and talking to renowned artists in a variety of computer imaging fields was not only enjoyable but extremely enlightening.

How well was the project was received by the general public? The interactive piece was tested by several people of various ages and occupations. Some had no prior knowledge of computers and some had a great deal. Most of these people found the project very informative and attractive. Many found it easy to navigate and quickly memorized the button sets I described earlier in the procedure section. People that attended the thesis showing gave me some very positive feedback. My project seemed to answer many questions they had concerning the development of digital imaging. Some told me it put things “into perspective” for them and others were surprised that the acceleration of images and software has only been over the last few years. The voice intros were very successful in creating a basic understanding of each section. Most of the users found the music suited the project and the voice work clear and expressive. The video clips in various sections seemed to add another dimension which people enjoyed. The movie buttons allowed them to view the movie as often as possible, stop it, step backwards or forwards if they wanted to replay certain part of the movie.
Many of the users enjoyed the movie introduction to the project since it helped to set a stage for the project's content. Everyone that has used the project appreciates the inclusion of buttons at the beginning of the project that allow the user to either play the intro or go directly to the Main Menu. They have all said viewing the intro once or twice is enough and then they would just want to use the project for information.
Future Recommendations

Since the project is a prototype, some areas need to be addressed to move the prototype to production. The following is a list of recommendations:

- The small "Help" available to the left on all screens needs to be completed for the novice user, one that does not know how to move a mouse, make a selection and point and click.

- In "The Electronic Studio" section, George Lucas' information needs to be added. This would include video clips of his movies that include computer special effects and digital images, also clips of interviews with him, a small quote and a brief biography. Sources for these clips and information are included in the Bibliography.

- Replace John Lasseter's photo image with a more professional image of him in both "The Electronic Studio" menu and on his information cards.

- Find and replace the "first scanned image" with the actual image of Kirsch's baby son in the "Timeline History" section. Since I couldn't locate the actual image, I made a temporary image as a place holder until it was found. Also, the image of the Kodak CD. I used an image of a regular CD temporarily.

- If additional dates and historical events are added to the "Timeline History" cards, the date buttons need to be made smaller or put on a diagonal, or replaced with a slider because of a limitation of space in the design.

- It would add an additional element of interest if video clip interview were added to all the artists in the "Pioneer's Speak" and "The Electronic Studio" information cards on each artist. This would allow the user to have a broader picture of the artist's personal experiences with digital imaging in his/her field of expertise.

- Pertinent artwork, dates, and other information can and should be added to "The Image Archive" and "Timeline History" sections. These sections were created as image databases and are meant to be updated when new information is collected.

- A Glossary of terms would be a helpful addition.
The changes computers have wrought are permanent and represent a watershed in the arts. The merging of art, design and technology has been irresistible for many. Although, computer graphics began thirty years ago, the artistic possibilities are just beginning to be understood. In reality, the technology has only been available to most artists for the last five to ten years with the advent of the microcomputer. Those who had access to research facilities in the early years and had the vision to explore have become the pioneers of an exciting, vastly growing new medium.
Appendix A - Interactive Project Outline

I. "Historical Development"

A. Research artist's images/ info
   - RIT library
   - Interlibrary loans (VAX)
   - Track bibliographic info

C. Update timeline
   - Cross reference existing timelines for date discrepancies
   - Software/Hardware development
   - C.G. development

D. Gather addresses, phone, fax numbers for companies
   - Call / write / fax companies for timeline verification

F. Need photos of computer scientists and inventions
   - Make list

G. Video? Discovery channel, etc.

II. "Spotlight on Artists Development"

A. Pioneers
   - Choose (2-4)

B. Current
   - Choose (5) areas of digital imaging and artists to represent

C. Gather addresses, phone/fax numbers for artists

D. Call / write / fax for:
   - Bio info
   - Images
   - Video
   - E-Mail "Info.Topic@siggraph.org" for artist contacts
Appendix A - Interactive Project Outline

III. Navigational Outline
   A. Create a basic navigational scheme
   B. Choose software

IV. Design visual layouts for interactive piece

V. Create interactive
   A. scanning and rescanning
   B. navigational buttons
   C. visual layouts
   D. video capture
   E. field information input
   F. music
   G. voice-over?

VI. Testing

VII. Complete written Thesis
<table>
<thead>
<tr>
<th>Digital Imaging Historical Timeline</th>
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</thead>
<tbody>
<tr>
<td>1st computer graphic images</td>
</tr>
<tr>
<td>1st computer generated film</td>
</tr>
<tr>
<td>1st competition for Computer Graphics</td>
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</table>
### Digital Imaging Historical Timeline

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<table>
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<tr>
<th></th>
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<tbody>
<tr>
<td>1st large scale CG exhibition-&quot;Cybernetic Serendipity&quot;</td>
<td>1st real time film animation</td>
<td>GRASS 1st microprocessor</td>
<td>Aaron drawing machine Image Processor</td>
<td>Electronic Visualization Lab - Palo Alto Research Center Videodiscs</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fractal Geometry</td>
<td>Digital Video Effects Device</td>
<td>Paint System</td>
<td>Bump Mapping</td>
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Digital Imaging Historical Timeline  continued....

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tr>
<td>1980</td>
<td>Still Video Camera</td>
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<td></td>
<td>MTV</td>
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<tr>
<td></td>
<td>IBM PC</td>
</tr>
<tr>
<td></td>
<td>Ray Tracing</td>
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<tr>
<td></td>
<td>SIGGRAPH Art Show</td>
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<tr>
<td></td>
<td>ADO</td>
</tr>
<tr>
<td>1981</td>
<td>HyperCard</td>
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<tr>
<td></td>
<td>desktop scanner</td>
</tr>
<tr>
<td></td>
<td>Adobe Illustrator</td>
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<tr>
<td></td>
<td>INTEL chip 80860</td>
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<td></td>
<td>Kodak announces Photo CD</td>
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<td></td>
<td>Photoshop 1.0</td>
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<tr>
<td>1982</td>
<td>Megaprint</td>
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<tr>
<td></td>
<td>Mona Lisa experiment</td>
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<tr>
<td>1984</td>
<td>F.A.S.T.</td>
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<tr>
<td></td>
<td>Kodak 7700 TD1 printer</td>
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<tr>
<td>1986</td>
<td>1987</td>
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<tr>
<td>1989</td>
<td>1990</td>
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# Thesis Work Schedule - Christy Brown

<table>
<thead>
<tr>
<th>Date</th>
<th>Task Description</th>
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<tbody>
<tr>
<td>W/O 2/13</td>
<td>Letters, faxes, etc. sent</td>
</tr>
<tr>
<td>2/20</td>
<td>Phone calls/ choose artists/ complete outline with photos / interlibrary loans/ design map</td>
</tr>
<tr>
<td>2/27</td>
<td>Navigational outline &amp; Interface design</td>
</tr>
<tr>
<td>3/6</td>
<td>*Begin interface, committee meeting</td>
</tr>
<tr>
<td>3/13</td>
<td>Spotlight on artist bio info / work images/ photos / video gathering complete</td>
</tr>
<tr>
<td>3/20</td>
<td>Video capture</td>
</tr>
<tr>
<td>3/27</td>
<td>Scanning</td>
</tr>
<tr>
<td>4/3</td>
<td>MacroMind front end</td>
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<tr>
<td>4/10</td>
<td>Music</td>
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<tr>
<td>4/17</td>
<td>Complete interface, committee meeting</td>
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<tr>
<td>4/24</td>
<td>Testing</td>
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<tr>
<td>4/29</td>
<td>Reception 7AM-9PM</td>
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</table>

* Interface work ongoing...
Appendix D - Project Layout

This is a map of this project. Click on the area you wish to go to...
Appendix E - Menu and Screen Layouts

Main Menu

A Visual History Menu
Appendix E - Menu and Screen Layouts

Image Archive Menu

Image Archive Screen Layout

Ben Laposky

Section #45
1950
USA

Goodman, p. 10
Timeline History
Screen Layout

1980

Ray Tracing

The computer technique most successful in
defining light and therefore most successful in
the depiction of convincingly realistic
scenes, is called “ray tracing”. The first
work on ray tracing was that of nuclear
physicist Philip Weinberger at NASA in the
late 1960s. However, Turner Whitted is
credited for developing ray tracing and
introducing it to the computer graphics
community at large in 1980.

Goodman, p. 114
Joshel & McCrea, p. 48

Appendix E - Menu and Screen Layouts

Pioneers Speak
Menu

Pioneers Speak
Screen Layout

“Science is the process of observing and understanding the universe. Improved observational tools provide better and quicker understanding.”

Melvin Prueitt
Physicist

Los Alamos
Laboratory
USA
Appendix E - Menu and Screen Layouts

The Electronic Studio Menu

The Electronic Studio Screen Layout
Appendix F - Hardware and Software Used

Hardware Used:

Macintosh Centris 650
- 24 MBs of RAM
- 230 MB hard drive
- internal CD ROM
La Cie 270 MB external hard drive
ClubMac 44 MB Syquest removable cartridge drive
Supermatch 17-T monitor
Hewlett Packard ScanJet IIc
Hewlett Packard DeskWriter
Mac Recorder
Quadra 800 with video board (for video capturing only)

Software Used:

System 7.1

Interactive Project:

- MacroMind Director 3.1.1
- Aldus SuperCard 1.6
- HyperCard 2.1
- Video Spigot 1.2.1
- Mac Recorder 1.03
- Sound Edit Pro 1.04
- Sound Edit
- Adobe Photoshop 2.5.1
- Hewlett Packard DeskScan II 1.6.1
- Stuffit Deluxe 1.0

Written Thesis:

- Quark Xpress 3.1
- MacWrite II 1.1v1
Voice Script for “Plugged In”

Animated Introduction

Digital imaging. Art and technology. Is it a marriage made in heaven? From it’s crude beginnings, it has developed lightning speed. With the advent of the micro computer, the art of digital imaging and manipulation has exploded and exceled the use of technology as a medium for the enterprising artist.

Though still in it’s infancy, digital imaging is already revolutionizing the way art is conceived, created and perceived. Not long ago the introduction of quick drying acrylic paints was hailed as a major breakthrough. Today, another medium allows us to expand our aesthetic possibilities-the computer.

When did it all begin? How far have we come? Where is it going? Prepare to investigate the answers to these questions and more...

“Plugged-In”...a visual exploration of the last forty years of digital imaging

Main Menu

This interactive presentation is divided into four main sections; each designed to give you a better understanding of how this digital imaging has evolved and a sense for where it is going. Please make your selection by clicking on an area of interest.
A Visual History Menu

This section is divided into two main parts: The “Image Archive” displays artwork created during a given time period. The “Image Archive” is provided to give you a visual sense of “how” electronic image making has evolved.

“Time Line History” is a synopsis of prominent historical events in the field of digital imaging. “Time Line History” reveals “why” things evolved given the technology of the period.

Please make your selection.

Image Archive Menu

(1950-1970)
The first archive explores the genesis of digital imaging and the creation of the very first images. Scientists called themselves artists and artists called themselves scientists. “Is it Science or is it Art?

The second explores the images produced on mainframes and minicomputers in some of the greatest labs around the world, where a few fortunate artists had access to this burgeoning technology.

(1980-1990)
Finally, in the last archive, an explosion of images from the art community provides us with proof that digital imaging is here to stay. With the advent of the micro computer and its software, most artists now have the ability to explore this new medium.
Timeline History Menu

(1950-1970)
This time period explores the initial technological advancements that were made in the area of digital imaging, highlighting some of the important pioneers and early events.

In the second time period, software and hardware development accelerates with artists and scientists working together.

(1980-1990)
The eighties make the micro computer available to almost everyone. Art and technology find a place in the home. Micro software and hardware makes the seamless fusion of science and art develop at a staggering rate.

Pioneers Speak Menu

This section provides a look at three pioneers of digital imaging and the images they produced during the developmental years. Much is owed to these artists/scientists. For without them, we would not have the vast store house of software and hardware created with the artists’ needs in mind.

The Electronic Studio Menu

In this section, you can explore the work of artists in various disciplines employing electronic technology. Included are quotes, biographical information and images designed to provide you with insight on how they explore digital imaging and why it moves them.


*From Star Wars to jedi.* produced and directed by CBS/FOX Video. 65 min., CBS/Fox Video, 1989, videocassette.


Interview with John Lasseter, produced and directed by Danish National Television, 1994, videocassette.


Selected Bibliography


