SuperPaint:
An Early Frame Buffer Graphics System

Richard Shoup

The union of digital computing and video was made possible by high-density integrated memories in the early 1970s. This new technology led Xerox PARC researchers to develop SuperPaint, the most famous of the early pixel-based frame buffer systems and one that portended a significant part of the future of computer graphics in television by illustrating the Pioneer spacecraft missions to Venus and Saturn.

In the early 1970s, integrated-circuit memories of significant size (1 Kbit and greater) became available. These chips made it practical for the first time to build a digital memory system—specifically, what came to be known as a frame buffer—containing enough bits to hold a standard video image. Minimally, a video image contained 640 pixels horizontally, 480 pixels vertically, and 8 bits in depth, for a total of 307,200 bytes.[1] This development in turn opened the door to the now-familiar world of pixel graphics and the use of digital technology in a wide range of imaging applications.

SuperPaint, one of the first pixel-based frame buffer systems, originated in the Computer Science Lab at the Xerox Palo Alto Research Center (PARC).[2] I initiated this project at PARC in 1972, designed most of the hardware for the system, fabricated it with help from a number of other lab members in early 1973, and coaxed it into displaying its first picture in early April 1973. I also wrote most of the software for the system over a period of several years. Alvy Ray Smith, Bob Flegal, and Patrick Baudelaire also wrote significant routines and made other contributions to the project.

Of course, the advantages of raster scan displays over line-drawing calligraphic displays were well known at the time. But from a larger perspective, we realized that the development of SuperPaint signaled the beginning of the synergy of two of the most powerful and pervasive technologies ever invented: digital computing and video or television.

At least two major problems had to be solved:

- making a digital frame buffer that operated at video rates and was fully compatible with video displays, cameras, recorders and other television technology, and
- finding ways for a human user to create and interact with full-color 2D images and, later, animations.

The former required some clever engineering. For the latter, we borrowed heavily from well-developed painting, graphic arts, and animation techniques in traditional media.

Hardware description

The SuperPaint frame-buffer memory system consisted of 16 printed circuit cards filled with 2-Kbit shift register chips (Intel 2401)—altogether, $640 \times 486 \times 8$ bits. We used shift register memories rather than the just-introduced 1-Kbit dynamic RAM parts (Intel 1103) because of their significantly higher bit density (more than a factor of 2), lower cost, and established reliability.

The entire memory recirculated as one long 307,200-pixel shift register, which was shifted synchronously with the video display at standard television scan rates. Thus, any particular pixel in the memory could be accessed only when the desired scan line and pixel time rolled around—an entire frame time of 33 ms in the worst case. (This was not as disadvantageous as it sounds, as will be explained below.) The pixel clock was 83 ns, which at standard video scanning rates produces square pixels on the display. By adopting standard video parameters, we could use readily available television studio monitors, record the output signal on available videotape or videodisk recorders, and transmit it on existing closed-circuit or broadcast television channels.
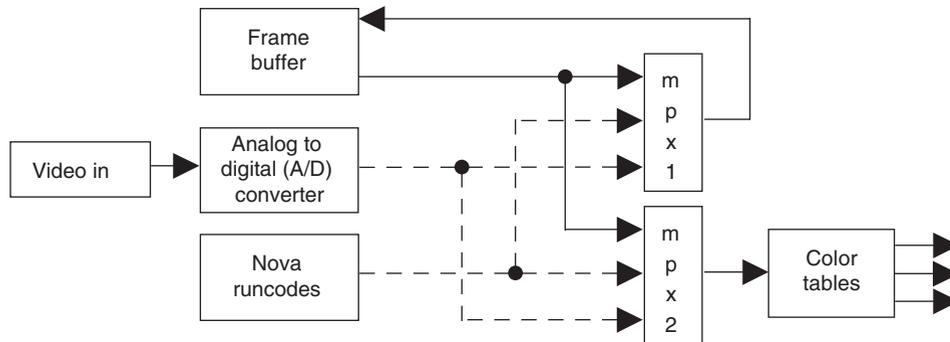
This synchronous recirculation structure also

Figure 1. Block diagram of the SuperPaint memory system. Solid lines show the paths used during static display. Courtesy of Richard Shoup.

permitted writing into the frame buffer in real time from any external standard video source such as a camera or tape recorder. Figure 1 shows the data paths of the frame buffer including the shift-register memory, the computer interface (discussed later on), and video inputs via a real-time analog-to-digital (A/D) converter.

Two multiplexers, operated on a pixel-by-pixel basis, controlled the flow of pixels. Multiplexer 1 controlled data flowing into the image memory, taking its input from either the computer, the video input stream, or the memory for recirculation. In addition to computer-controlled switching, several experimental circuits were added from time to time to implement other pixel-rate functions, such as area filling and various kinds of pixel value replacement.

Multiplexer 2 controlled data sent out to the color lookup tables ($256 \times 8 \times 3$ static RAMs producing separate red, green, and blue streams) and thus to the digital-to-analog converters (D/As) and out to the video displays. This multiplexer could also switch at full pixel rate among the three input streams, thus allowing pixel-by-pixel control of overlay effects such as brush-over-canvas and video-input-over-canvas, without storing the result of this pixel stream merge into memory.

Eventually, a second set of color tables and D/As were added to the system so that separate menu and canvas displays could be supported, each driven by a selection from the 8 bits in each pixel. Typically, 4 bits were allocated to each of the two images. Then, judicious setting of the color tables permitted several display modes, including separate menu and canvas images on two monitors, switching between menu and canvas on a single monitor and a transparent menu overlaid on canvas on a single monitor.

Using the color tables, one could easily cre-

ate and change various palettes of displayed colors to suit the artist's intent. By changing color-table definitions rapidly under program control, we also implemented a limited but surprisingly useful array of animation functions and effects.[3] In particular, the program could change the color of a large number of pixels on the screen much more quickly than writing new values for all of them into memory.

A commercially available analog RGB-to-NTSC (red-green-blue–to–National Television Standards Committee) encoder provided standard composite video output for broadcast or recording to videotape. The system could also be synchronized to an incoming video signal by means of its own sync generator—an essential feature for any real-world production studio or on-air operation.[4] An 8-bit real-time A/D converter provided monochrome video input from a video camera or videotape recorder.

A Data General Nova 800 minicomputer served as the system controller, which we programmed using the BCPL language (a predecessor to C) and some assembly code. Two Diablo 31 disk drives were attached, with removable 2-Mbyte cartridge disks.

From the Nova controller, a run-length-encoded read/write interface permitted specification of a scan line number (y coordinate), a pixel number (x coordinate), and a run length of up to 255 pixels. Although a controversial choice at the time, this shift-register-based architecture and interface actually performed faster on most typical tasks—even random line drawing—than the PARC Alto machine built at the same time using the latest 1-Kbit DRAMs. By keeping a sorted list of pixel runs waiting to be written to the frame buffer, the software could efficiently utilize the runcode hardware as scan lines became available in the raster scan recirculation. With standard solid-color paint brushes, for example, only one run per scan line

Figure 2. SuperPaint frame-buffer system rack. Courtesy of Richard Shoup.

was needed regardless of brush size, and painting could always take place at the full 30 frames/second rate.

At the top of the 5-foot equipment rack shown in Figure 2 is the 8-bit video digitizer (a full 6 inches of rack space and a cost of more than $12,000 at the time), a set of fans, and the SuperPaint frame-buffer memory card cage. The space just below would soon be occupied with another card cage containing the control cards, color lookup tables, D/As, and the minicomputer interface. A second set of fans and several power supplies are at the bottom of the rack.

The shift-register memory card (16 copies) was a printed circuit board, while all control and data-path circuitry was implemented using Augat-style wirewrapped prototype cards. Originally, there was to have been an additional cage of memory cards providing a second 8-bit frame buffer in the center of the rack, but this was deemed too expensive and was never added. A second 5-foot equipment rack held the Data General Nova 800 minicomputer, two Diablo 31 disk drives, a cage of miscellaneous interface cards, and additional power supplies.

Figure 3a shows the frame-buffer backplane; Figure 3b is the first picture captured in the SuperPaint frame buffer when it came to life in April 1973. Input was from a monochrome video camera pointed at the author. Judging from the clipleads on the backpanel, the hardware still had a few bugs at this time. To trigger the capture of this image, I pulled a cliplead off the backpanel using my knees! The card I'm holding says, "It works! (sort of)." The interface to the Nova 800 controller had not been even plugged into the system yet at the time this image was captured. To avoid losing this image, I was forced to plug the interface card in and debug it and its software with the power still on. Later, I was able to clean up some of the missing bits in the image with a small heuristic program.

Software description

Before any paint programs existed for the SuperPaint frame buffer, I wrote a "jaggie removal" program to generate smooth straight lines at any angle, without the jagged stairsteps always associated with raster computer displays at that time. Today, this well-known technique is called antialiasing. The algorithm, written in Nova assembly language, imitated a standard video camera by computing an approximation to the intersection of the desired line with an imaginary circular gaussian scanning spot. I was in a hurry to implement this technique because I had already submitted a paper on it.[5] Fortunately, the results were even better than anticipated, as seen in Figure 4.

Over the next several years, a lot of experimentation went on concerning how to use the pen and tablet for both painting and for control functions, how best to control and select brushes, and how to edit pictures and color spaces. Other experiments dealt with dynamic interaction and with the system's color-table animation capabilities. Details of some of the system's operation and applications have been published elsewhere.[6,7]

After many versions, the menu evolved to include the functions shown in Figure 5 such as Paint (the paint brushes on the left and right); Shrink 2X, Expand 2X, Move, and Copy (center-left section); Store and Load (bottom

Figure 3. (a) The SuperPaint frame buffer backplane, with clipleads. (b) First image: "It works! (sort of)." Courtesy of Richard Shoup.
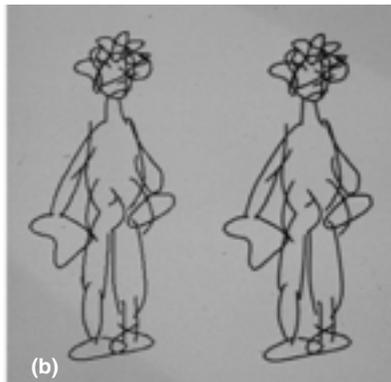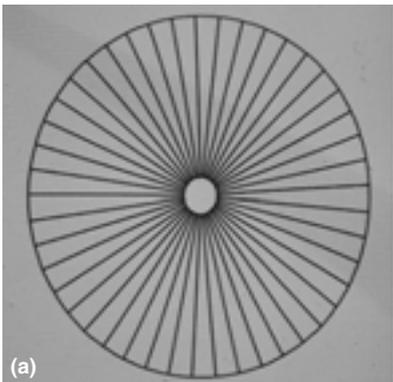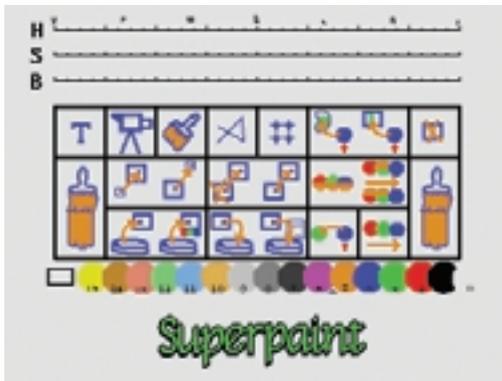

Figure 4. (a) Antialiased wagon wheel; (b) Original and smoothed drawings: *Two Guys* by Bob Flegal (1973). Courtesy of Richard Shoup.

Figure 5. *SuperPaint menu* **by Richard Shoup (1977).**

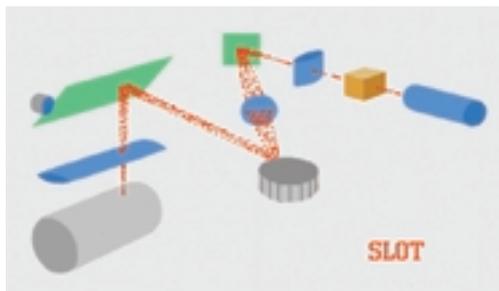**Figure 6.** *Black Girl* **by Fritz Fisher (1973). Courtesy of Richard Shoup.**

Figure 7. *SLOT animation* **by Bill Bowman (1974). Courtesy of Richard Shoup.**

Figure 8. "Over Easy" graphics by Damon Rarey (1977). Courtesy of Richard Shoup.

center); Text, Video In, Make Brush, Draw Lines, Gridding, Area Fill (top row); and various forms of color table animation (right-center). Some functions were qualified by a rectangular area defined by dragging two corner-shaped markers. During use, currently available brush shapes were displayed along the bottom of the menu in place of the SuperPaint title shown in this figure.

Most useful were the animation functions and effects made possible by the color lookup tables. These included Color Cycle (for flowing motions), Reveal (for progressive development of an illustration), and Step (for stepwise motion). These are detailed elsewhere.[3]

Applications and anecdotes

The following images and comments will serve to illustrate some of the early experiments and applications of SuperPaint.

For the first paint program, the runcode hardware wasn't working yet, so for a short period all paint brushes were one pixel wide (and any height)! Artist/mathematician Fritz Fisher had taken a job as a night guard at our building in order to obtain access to the system, and images like the one in Figure 6 often greeted us in the mornings.

Figure 7 was the first full animation done on the system. It was created one frame at a time by artist/designer Bill Bowman using a separate real-time video disk system (300 frames of 4 analog video channels) attached to the RGB outputs of SuperPaint. Unfortunately, this disk had a habit of crashing its heads on a regular basis, despite heroic efforts on the manufacturer's part. We were lucky to complete this animation of the Scanned Laser Output Terminal (SLOT), the first laser printer built by Gary Starkweather at PARC.

One of the first applications of computer graphics in broadcast television was the use of SuperPaint in the PBS television series "Over Easy," produced in the late 1970s at KQED in San Francisco. The producers of the show wanted some innovative graphics and animation for their new series and had heard about some interesting graphics work at Xerox PARC. They came to visit, and thus Damon Rarey and I first met and became long-time collaborators. Damon produced many graphics and eye-catching animations, such as those in Figure 8, that were used regularly in the "Over Easy" show—at a cost far below conventional methods of the time.

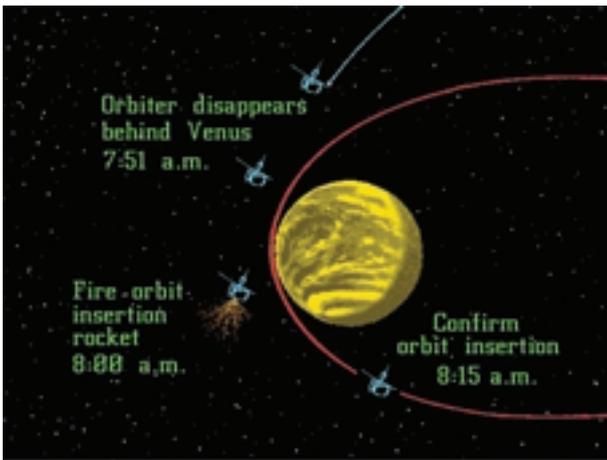**Figure 9. SuperPaint on location at NASA Ames. Courtesy of Richard Shoup.**

Figure 10. *Pioneer Venus orbit insertion* **by Damon Rarey (1978). Courtesy of Richard Shoup.**
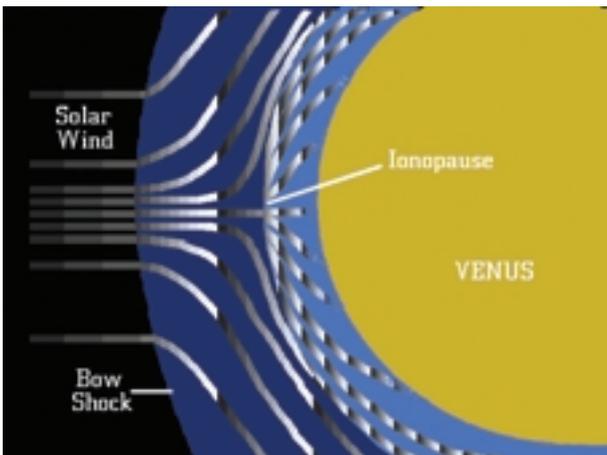

Figure 11. *Solar Wind* **by Damon Rarey (1978). Courtesy of Richard Shoup.**

In December of 1978, we had our first real test of SuperPaint's potential during NASA's Pioneer mission to Venus. We transported the entire SuperPaint system to nearby Ames Research Center in Mountain View and set it up, as Figure 9 shows, near the NASA pressroom and mission control during the spacecraft's encounter with the planet. Rarey produced dozens of colorful graphics and animations illustrating mission progress and onboard science that were fed to NASA-TV via standard NTSC video. This was a godsend for NASA public relations, because the Pioneer spacecraft was not equipped with an imaging camera. The chalkboard in Figure 9 shows a tally of the seemingly unending series of demonstrations we gave to mission scientists, press, and numerous other visitors from around the world.

The color-table-Reveal animation in Figure 10 showed insertion of the Pioneer Venus spacecraft into orbit around Venus during the planetary encounter. This animation was used on the live NASA-TV program originating from Ames during the mission. Unfortunately, the director cut to it just at the moment the Mission Control scientists were cheering the orbit's confirmation, and some news organizations complained mightily that we had stepped on the live video with some new-fangled computer graphic.

The color-table-Cycle animation in Figure 11 showed the flow of particles emanating from the sun as they passed around Venus, which the Pioneer probes were designed to detect and measure. The NASA scientists, and especially the public relations people, were overjoyed to have a way to explain the Pioneer mission's exciting science results to the public.

Although most of our NASA graphics were serious science illustrations, occasionally we tried to be simply entertaining. After surviving the plunge through the atmosphere of Venus, one of the Pioneer probes mysteriously stopped transmitting just after landing on the hot Venusian surface. Damon and I thought perhaps we knew what had become of the probe, as we illustrated in Figure 12. The hot gasses shown in the animated Venusian sky in this figure flowed continuously through the use of color table cycling.

A year after Pioneer Venus, in 1979, we were invited to bring SuperPaint back to NASA Ames again to play a similar role in a subsequent Pioneer spacecraft mission to the planet Saturn. During both of these planetary encounters, our animations were seen on nearly every major television network around the world. On one occasion, Rarey did a live interview and SuperPaint demonstration on Italian network

television from our location at Ames.

In late 1979, Rarey and I left Xerox and founded the company Aurora Systems in an area of San Francisco that has since become known as Multimedia Gulch. At Aurora, we developed several further generations of painting and animation systems, manufactured and sold these systems, and supplied computer graphic services for the video broadcast and production markets throughout the 1980s.

Current status

At present, the complete SuperPaint system resides in the permanent collection of the Computer Museum History Center at Moffett Field in Mountain View, California. On occasion, it is still operational.[8]

Acknowledgments

References

1. SuperPaint was not the first such frame buffer nor the first digital paint program. For definitions and additional background relating to early frame buffers and painting systems, see the accompanying article in this issue by Alvy Ray Smith, "Digital Paint Systems: An Anecdotal and Historical Overview."

2. M. Hiltzik, *Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age*, HarperBusiness, New York, 1999.

3. R. Shoup, "Simple Animation by Changing Color Definitions," *Proc. ACM SIGGRAPH Conf. Computer Graphics and Interactive Techniques*, ACM Press, New York, 1979.

4. To our knowledge, SuperPaint was the first fully video-compatible pixel-based computer graphics system.

5. R. Shoup, "Some Quantization Effects in Digitally-Generated Pictures," *Soc. for Information Display Symp. Digest*, Soc. for Information Display, San Jose, Calif., 1973.

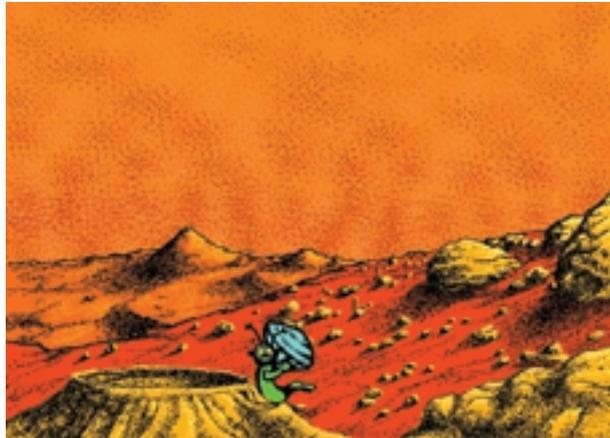6. R. Shoup, "Menu-Driven User Interfaces for Videographics," presented at the SMPTE 17th Television Conf., San Francisco, Calif., Feb. 1983. Published in *SMPTE J.* and *SMPTE Video Pictures of the Future*, Soc. of Motion Picture and Television Engineers, Scarsdale, N.Y., June 1983.

7. R.G. Shoup, "Some Experiments in Television Graphics and Animation Using a Digital Image Memory," SMPTE 13th Television Conf., San Francisco, Feb. 1979. Published in *Digital Video*, vol. 2, Soc. of Motion Picture and Television Engineers, Scarsdale, N.Y., Mar 1979, pp. 88-98. Republished in *Datamation*, May 1979.

8. If you would like to assist in getting the SuperPaint Nova 800 in full working order again, or can otherwise read Diablo-31-style 8-sector packs written by a Decision disk controller circa 1972, please contact the author at rgshoup@rgshoup.com.

Figure 12. *Green Guy* by Damon Rarey (1978). Courtesy of Richard Shoup.

Richard G. Shoup is cofounder and president of the Boundary Institute, a nonprofit research center for the study of leading-edge physics and mathematics (http://www.boundaryinstitute.org). Shoup obtained a BSEE and a PhD in computer science at Carnegie Mellon University. His doctoral dissertation (1970) was one of the first to explore field-programmable gate arrays and the idea of restructurable computing. He was awarded an Emmy in 1983 by the National Academy of Television Arts and Sciences for his graphics work at Xerox PARC in the 1970s. In 1998, he was also honored with an Academy Award for Scientific and Technical Achievement by the Academy of Motion Picture Arts and Sciences.

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