Digital Paint Systems
Historical Overview

Technical Memo 14[1]

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Introduction

The period I will cover is from the late 1960s to the early 1980s, from the beginnings of the technology of digital painting up to the first consumer products that implemented it. I include a little information about major developments in the later 1980s. Two surveys that cover this later period fairly well—when the emergence of the personal computer completely changed the software universe—were both published in the magazine **Computer Graphics World** [Smith82a, Robertson88]. My emphasis, of course, is on those systems I knew firsthand.

I begin with a simple timeline of programs and systems. I will attempt a weighting and a "genealogy" of these in a later section, where I will also narrow the field to those painting systems that have directly affected the movie industry.

Definitions

I will distinguish between digital paint programs and digital paint systems. The idea is to provide a rough measure of the depth of functionality provided. A digital paint *program* does essentially no more than implement a digital simulation of classic painting with a brush on a canvas. A digital paint *system* will take the notion much farther, using the "simulation of painting" as a familiar metaphor to seduce the artist into the new digital, and perhaps forbidding, domain. Of course, they are both programs, but I will use the term "system" to imply much more depth, a more "complete" system. In fact, a system might even use several well-integrated programs.

The world of computer assisted picture making can be divided cleanly and simply into two distinct worlds: *geometry-based* graphics and *pixel-based* graphics (also known as *imaging*), depending on how the original data is stored[3]. Standard

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[1] Originally prepared for the Academy of Motion Picture Arts and Science in response to the solicitation, dated May 2, 1997, of information on Digital Paint Systems by the Digital Imaging Technology Subcommittee.

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[3] I believe that one of the reasons Pixar (and related endeavors) has been so successful is that we fully pursued both halves of the computer "picturing" world.

computer-generated imagery—as in ***Jurassic Park***, for example—is geometry based. The digital paint system captures the other half of graphics, the pixel-based half[4].

So a digital paint system is a set of tools for dealing with pixels. Certainly, a digital paint program is one of these tools. To be very careful, I could narrow the definition of digital painting—from simply a simulation of classic painting—to include any image processing (ie, pixel processing) function that is applied to pixels under *hand control*—for example, with a mouse or a stylus on a tablet. I prefer not to do this, however, to better include, say, all of Dick Shoup's ***Super-Paint*** system, under one heading. To support this broad definition of digital paint system, I ask that the reader consider modern consumer products that are heirs to the technology being discussed here: Adobe ***Photoshop***, Microsoft ***Image Composer***, the Corel ***Draw*** suite, and so forth. Suffice it to say that when I use the word "system" I am implying much more functionality than when I use the word "program".

A word about bit depth. There are five bit depths in the programs and systems discussed below: 1-bit, 3-bit, 8-bit, 24-bit, and 32-bit. These correspond respectively, to 2 colors (black and white), 8 colors, 256 colors, 16.7 million colors, and 16.7 million colors plus 256 levels of transparency each. I essentially will disregard the 1-bit and 3-bit systems. The 8-bit, or 256-color, systems made digital painting a real tool in video. The 24-bit and 32-bit paint systems are required for film use. The difference between 24-bit and 32-bit systems is whether an extra channel (the "alpha channel"), carrying transparency information, is available for all images at all times. In both kinds of systems, transparency effects such as airbrushing and soft-edged compositing were possible, but only 32-bit systems as a matter of course always generated an alpha channel with every image. In other words, the alpha channel was painted when the color channels were painted, not as a separate task.

Timeline for Color Paint Programs and Systems

[1969-70] Joan Miller implements a crude paint program on a 3-bit framebuffer at Bells Labs [Miller78].

[1969-70] W J Kubitz and W J Poppelbaum implement the "tricolor cartograph" with eight fixed colors, a crude paint program[5] [Kubitz69].

[1972-73] Richard G Shoup creates ***SuperPaint***, the first complete 8-bit paint system, including hardware and software, at Xerox Palo Alto Research Center [Shoup75a, Shoup75b, Shoup79].

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[4] It should be noted that the two worlds intersect in some places, the most notable being in so-called texture mapping, where a digital image, often painted, is "wrapped" onto a 3-dimensional geometric surface to give it the appearance of reality.

[5] And, possibly, partially or wholly analog.

[1974]   James Blinn writes 8-bit paint program ***Crayon***[6] for the new Evans & Sutherland framebuffer[7] at the University of Utah in December 1974 [Smith78, Leavitt76, Blinn97].

[1975-76] Garland Stern writes 8-bit paint program for the Evans & Sutherland framebuffer at the University of Utah [Smith78]. He brings it with him to the New York Institute of Technology in 1975[8] [Stern97, Blinn97].

[1975-76] Alvy Ray Smith creates 8-bit paint system ***Paint*** at the New York Institute of Technology, also for an Evans & Sutherland framebuffer, later for the Genisco framebuffer. ***Paint*** is sold to Ampex in late 1976[9] [Smith78].

[1976]   Jules Bloomenthal creates an 8-bit paint program at the University of Utah, Evans & Sutherland framebuffer, after seeing Blinn's and Stern's programs [Blinn98].

[1976]   Marc Levoy programs an 8-bit paint system for the Evans & Sutherland framebuffer at Cornell University [Levoy79, Smith78].

[1976]   Alvy Ray Smith creates an 8-bit paint system ***BigPaint***, the first for pictures larger than video resolution, on Evans & Sutherland and Genisco framebuffers [Smith78, Negroponte79].

[1976]   Massachusetts Institute of Technology students[10] implement an 8-bit paint program on MIT's own framebuffer [Smith78].

[1977]   Alvy Ray Smith implements first 24-bit (RGB) paint system ***Paint3*** at the New York Institute of Technology, for three Evans & Sutherland or Genisco framebuffers in parallel [Smith78].

[1977-78] Jim Blinn adapts Bloomenthal's paint program to his needs at the Jet Propulsion Laboratory in Pasadena. In particular, in 1977 he adds airbrushing that is later used to generate texture maps for his Voyager flyby simulation movies in 1978 [Blinn97].

[1978]   Alvy Ray Smith publishes first documentation of ***Paint, BigPaint,*** and (briefly) ***Paint3***, plus history of digital painting up until then, as tutorial notes for SIGGRAPH 78 [Smith78]. These notes plus [Smith79a] are used for several years at successive SIGGRAPH conference tutorials.

[1978]   Marc Levoy implements a specialized 8-bit program for painting (opaquing) animation cels, ***OPAQUE***. It preserves soft edges, using a

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[6] It had a fixed palette of 6x6x6 colors displayed at the bottom of the screen, variable sized rectangular brushes, and could save or restore images to or from files [Blinn97, Leavitt76].

[7] The night the E&S hardware first ran, in fact [Blinn97].

[8] Jim Blinn recalls that he had the program with him when he returned from a summer at NYIT [Blinn97].

[9] I have a dated notebook, from December 1976, covering the Ampex installation.

[10] I have been unable to retrieve the names of any of them, but see [Negroponte77, Negroponte79].

colormap technique[11], and is used in Hanna-Barbera animation production.

[1978-79] Alvy Ray Smith creates ***BigPaint3***, the 24-bit version of ***BigPaint***, and hence the first 24-bit paint program for higher than video resolution.

[1978-79] Marc Levoy implements a 24-bit paint system ***PAINT*** at Cornell University, on a 24-bit Grinnell framebuffer.

[1978-79] Ephraim Cohen implements ***ept***, an 8-bit or 24-bit paint program (it could do either), at the New York Institute of Technology, for Evans & Sutherland and Genisco framebuffers.

[1979] Ed Emshwiller creates ***Sunstone*** video using ***Paint*** (with assistance from Alvy Ray Smith, Lance Williams, and Garland Stern) at the New York Institute of Technology. This video is now part of many museum collections, notably the Museum of Modern Art in New York.

[1980] Richard G Shoup and Damon Rarey start the company Aurora Systems; they build and sell the ***Aurora/100*** digital videographic system, an 8-bit hardware and software paint system.

[1979-80] Marc Levoy, Bruce Wallace, and Chris Odgers implement digital imaging system for Hanna-Barbera based on the 24-bit Grinnell framebuffer. The system is still in use at Wang Studios in Taiwan, but the 24-bit paint program never made it into production use [Levoy97].

[1979-80] Thomas Porter, Rodney Stock, Larry Evans, Ken Turkowski, and Junaid Sheikh create ***Ampex Video Art (AVA)***, a commercial[12] 8-bit paint program and hardware. It took special care not to create aliased edges, using special colormap techniques (cf Levoy's ***OPAQUE*** above).

[1980-81] Jeff Burton adapts Ephraim Cohen's program to implement ***IMAGES13***, an 8-bit or 24-bit (depending on configuration) commercial paint program product for CGL, Inc[14], a subsidiary of the New York Institute of Technology.

[1980s][15] Richard Taylor and others implement ***PaintBox***, a 24-bit commercial video paint product for the English company Quantel, the first system to implement special-purpose hardware acceleration for digital painting. They later extend the resolution in the product ***Graphic PaintBox*** for use in print and film [Porter81d, Robertson88].

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[11] It had a specialized colormap structure that divided the available bitdepth into i bits for border colors, j bits for infill colors, and k bits for the anti-aliased transitions between these colors, $i + j + k = 8$ [Levoy97].

[12] The first commercial paint product. Shown on show floor of National Association of Broadcasters (NAB) convention in March or April 1980. Quantel ***PaintBox*** was shown in a suite.

[13] For Image Manipulation And Generation Electronic System [Porter81d].

[14] Named for the Computer Graphics Laboratory at NYIT.

[15] There has been a lot of bad blood between Quantel and the rest of the digital imaging community, even now being argued in legal patent battles. Since I have been personally involved in these arguments, I will not pursue the Quantel contribution here. [Added 20 Dec 98: Quantel subsequently lost its major paint patents, five of them, in a US court, in a suit against Adobe.]

[1981]   Gene Miller writes a paint system at the New York company Digital Effects for the ad agency J W Thompson. It ran on the Lexidata framebuffer and output to film.

[1981-82] Thomas Porter implements first complete 32-bit (RGBA) paint system ***Paint*** at Lucasfilm Ltd, using a 32-bit Ikonas framebuffer. It is used in ***Star Trek II: The Wrath of Khan*** [Smith82b], the first use[16] of digital paint systems in theatrical release films [Porter81a, Porter81b, Porter81c].

[1985-86] Mark Leather implements ***LayerPaint***, a 32-bit paint program, on the Pixar Image Computer at the Computer Division of Lucasfilm Ltd. He is awarded a technical Academy Award for its use in "wire removal" in 1994.

[1985-86] The Knoll brothers, Thomas and John[17], working at Lucasfilm, adapt Computer Division imaging functions, including painting, to create ***Photoshop[18]***, a 24-bit commercial imaging product (originally for the Mac), later purchased by Adobe[19].

[1986-88?] Tom Hahn (formerly with Dick Shoup at Aurora), Michael Shantzis, and Peter Nye implement ***CAPS[20]***, a digital animation system including cel painting, on the Pixar Image Computer at Pixar on a contract with Disney. They (and Disney personnel) are awarded a technical Academy Award for its use in animated feature films in the 1992.

[1990-91] Alvy Ray Smith writes ***Composer***, a 32-bit imaging system, with digital painting, at Pixar. Technology is spun off into startup company Altamira Software Corporation that produces ***Altamira Composer***. This is merged into Microsoft Corporation in 1994 where product is repackaged as Microsoft ***Image Composer***, a currently shipping 32-bit product with painting. A closely related sister product (based on the same principles) for photos is Microsoft's ***Picture It!***

Genealogy of Digital Paint Systems

One way to organize the programs and systems above is to show their lineage or genealogy. The principal stream, or mainstream, so far as movie production is concerned is this:

- Dick Shoup's ***SuperPaint*** (1972-73)
- Alvy Ray Smith's ***Paint*** and ***Paint3*** (1975-77)
- Tom Porter's ***Paint*** (1981-82)
- Marc Leather's ***LayerPaint*** (1985-86)

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[16] I believe.

[17] John still works for Lucasfilm. I understand that Thomas brought a background in image processing to bear on the product as well.

[18] I do not know it's original name.

[19] The Mac was not 24-bit capable until about 1989-90.

[20] For Computer Animation Production System.

- The Knoll brothers' ***Photoshop*** (1985-86)

There are many side streams too that I will list, but first I mention the developments that had no or little effect on this mainstream.

The Miller and Kubitz and Poppelbaum programs have not influenced the other programs or systems above. They both had only eight colors and were not systems, but merely programs, using the terminology introduced above.

I have not included any paint programs that painted only in black or white (1 bit) since they had no influence on the mainstream either. For example, I recall one such program at Xerox PARC while I was employed there in 1974.

The MIT system was not influential, at least not on the systems with which I am familiar.

Jim Blinn's program had no direct effect on me other than its influence, if any, on Garland Stern's program that he brought to NYIT in 1975[21]. The Stern program goaded me, from dissatisfaction, into writing my first system. For example, it had a strange stroking technique that I knew *not* to use: A stroke was started, and stopped, by clicking the tablet stylus once (down and up). This had the effect of feeling very good while stroking, since there was no pressure from the stylus tip back to the fingertips, but being very awkward for starting and stopping—causing unwanted jerks in the painted stroke. The stroking technique I used—and used by all subsequent programs—was the one I learned from Dick Shoup's system: Push down the stylus to start a stroke, drag it (under pressure) to paint, then release pressure to stop the stroke.

Jim Blinn's influence took a separate path. In 1977 he took the Jules Bloomenthal paint program from Utah to the Jet Propulsion Laboratory. Then, at the request of Evans & Sutherland, he took all his framebuffer software and installed it at the National Institutes of Health (NIH) in Washington (on an E&S framebuffer of course). This was in 1977. The principal system engineer at NIH with whom he worked was Tom Porter, who was probably seeing his first paint program. The proximity of JPL to Hollywood made Jim's lab probably the first exposure of many film people to digital imaging technology [Blinn97].

The Quantel stream had no influence on the mainstream above. It is not clear if it was influenced by the NYIT developments. They made trips to NYIT, attended tutorials by NYIT personnel, and acknowledge having my paper [Smith78], but legal precedence matters have obfuscated this part of the history.

I don't know of any connection between the Digital Effects paint program and the mainstream.

One definite side stream to the main lineage above is of course the Aurora Imaging system ***Aurora/100***. Later Tom Hahn left Aurora to join Lucasfilm and

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[21] Jim Blinn recalls that Garland's program supplanted his own at Utah, after Garland's return from NYIT, because of a larger feature set [Blinn97]. Both Garland and Jim recall that the two programs were separate developments [Blinn97, Stern97].

write the ***CAPS*** system there under contract to Disney (a deal, and a hire, I negotiated).

Another important side stream is that started by Marc Levoy at Cornell and leading to Hanna-Barbera. Marc and his colleagues were some of the first and frequent visitors to our lab at NYIT. I believe it is accurate to say they were inspired by what they saw there, although their stream was essentially a separate development after that.

Another stream, that comes back into the mainstream, is the Ampex one that began with the sale of my ***Paint*** program to Ampex[22] and its influence on ***AVA*** and particularly Tom Porter. As the new Director of Computer Graphics Research at Lucasfilm, one of my first hires was Tom Porter to implement our Lucasfilm paint program, knowing that he understood my "style". And later Mark Leather, hired from Ampex as a hardware engineer at Pixar, surprised us by writing the first paint program, ***LayerPaint***, on the new Pixar Image Computer (that he helped design) which has been used by Lucasfilm for movie production. He had worked on the hardware for ***AVA*** at Ampex.

My colleague Ephraim Cohen took a lot of the NYIT ideas, including those from my ***Paint*** and ***Paint3***, and brewed them a different way[23] to produce ***ept*** which begat ***Images*** and later (early 1990s) a system ***Cricket Paint*** that Ephraim wrote under arrangement with Computer Associates. In particular, he noted that painting was just a hand-driven form of image composition[24] and used this as an organizing principle.

The ***Photoshop*** connection is not well-known. I recall that my Lucasfilm colleague David DiFrancesco kept urging me to go see what the Knoll brothers were doing, in another Lucasfilm building, with "our stuff", putting it onto the Mac. He told me it was rather impressive, but I couldn't be bothered with tiny little machines at the time—a mistake I corrected many years later by adopting the Windows platform. The Knoll brothers shopped their creation for a while, finally getting some support from a startup company called BarneyScan. Then John Warnock saw it and arranged to have Adobe market the system, grandfathering, presumably, BarneyScan. The dates I give above (1985-86) are approximate, based on the fact that we spun out Pixar from Lucasfilm in 1986.

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[22] I personally installed ***Paint*** at Ampex in December 1976, working with Junaid Sheikh.

[23] In 1977 Ephraim collected framebuffer-to-framebuffer and file-to-framebuffer copy and composite routines together into a general-purpose ***Copy*** program. In 1978 he added tablet control to this to get painting, which inherited 8-bit or 24-bit mode, antialiasing, airbrushing, etc from the ***Copy*** program. In 1978-79 he fleshed this on out into his ***ept*** painting system [Cohen97]

[24] I had also noted this. See [Smith79a]. Dick Shoup based his Aurora products on this concept too [Shoup97].

Dick Shoup: SuperPaint

Dick Shoup's ***SuperPaint***[25] was a revolutionary program—simple and intuitive, the parent of all modern paint programs—with 256 colors selectable from 16.7 million, a palette, a colormap, video in and video out, a tablet and stylus, variable paintbrush size, animation, video magnification, image transformations, image file input and output, all the basics of a modern paint program—eventually earning Dick (and Xerox) an Emmy in 1983.

I began using ***SuperPaint*** in February, 1974. My small contribution to it was the RGB to HSV (aka, HSB) color transform, for more intuitive color choice by artists. I used the system to create my first digital animation videotape, ***Vidbits***, in 1974.

Alvy Ray Smith: Paint and Paint3

Paint (and its high-resolution extension, ***BigPaint***) is clearly described in [Smith78]. Of more pertinence here is the full-color, 24-bit version, ***Paint3***, that was only briefly described in Appendix B of [Smith78]. It was the first paint system to have 16.7 million colors. This permitted airbrushing and full compositing of any image over any other, and these were both implemented. In fact, using the notion introduced in ***Paint***, that any image can be used as a "brush" to paint on any other image, ***Paint3*** allowed brushes of any shape, including the "shape" of its transparency. Airbrushing fell out of this observation by easy default: simply choose a brush that is opaque in the center and drops off gradually to transparent around its edges. **BigPaint3** was the high-resolution extension of ***Paint3***.

Paint3 featured 16.7 million colors, airbrushing, tablet and stylus control, variable paintbrush size and shape (any shape, with any pixel-by-pixel opacity variation), image save and restore (of either 8-bit or 24-bit images), a disappearing palette (it disappeared after color selection), color selection from anywhere on the screen (not necessarily the palette), video magnification, palette selection (for convenience only) from palettes of arbitrary colors, tint and value adjustment of colors, color mixing (or smearing, as I called it), 24-bit color fill, and other functions. There was a button that allowed any other 24-bit program in my system to be run from within the paint program (hence my definition of system). This included a full-featured image restoration program that handled (after 1977) alpha channels (called **Getpa**) and an anti-aliased geometric rendering program (by Malcolm Blanchard) called **Sketch** (extended by me to 24-bits as ***Sketch3***).

I conceived of doing ***Paint3*** while lying bored in a motel room in Redwood City, CA, after completing installation of ***Paint*** at Ampex in December 1976. I wrote it immediately upon returning to NYIT in December 1976 to January 1977.

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[25] Dick actually called his environment the Color Video System [Shoup74a, Shoup74b], including a paint program called Paint. He added program SuperPaint to the system in February, 1975 [Shoup75b]. I refer to the entire system as ***SuperPaint*** for convenience. The complete system is in the permanent collection of the Computer Museum of Boston (its Santa Clara branch) and is still functional.

Tom Porter: Paint

The Lucasfilm *Paint* system was designed to be suitable for motion picture use. Hence Tom paid a great deal of attention to problems of image resolution, color fidelity, and anti-aliasing [Porter81a, Porter81b, Porter81c]. He began the system development during 1981, and completed it in January 1982, in time for use in the production of the *Genesis Effect* sequence[26] for the Paramount movie ***Star Trek II: The Wrath of Khan***. Matte painter Chris Evans of Industrial Light & Magic (ILM) used the paint system in early 1982 to create the ground and soft-edged clouds that were texture mapped onto the receding planet. The movie opened in June of 1982. See [Smith82b] for details of the production, including reference to Tom's system.

This was the first use of digital paint systems for movie production at Lucasfilm. I believe it was also the first use of them in theatrical release motion pictures. I believe *Paint* was also used in the production of the special effects for "the stained-glass man" in the 1985 Amblin Productions film ***The Young Sherlock Holmes***.

Major features of the Lucasfilm *Paint* system were: arbitrary resolution, creation and manipulation of the alpha channel with every stroke (ie, it was a full 32-bit system—the first, I believe—with 16.7 million colors and 256 levels of transparency for each one of them), and careful attention to anti-aliasing and compositing. Tom Porter reports the existence of a March, 1981 Lucasfilm technical memo about the proposed architecture [Porter97]. He says there was a surprising amount of planning regarding the handling of large (movie-resolution) images.

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[26] Which I directed.

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