Computer Graphics for Scanned Laser Displays

By Patrick Murphy and William R. Benner, Jr.

Projected laser displays, such as those for laser light shows, often use computer-drawn graphics, which are scanned onto the screen. These vector drawings have restrictions imposed by the laser projection equipment. Conventional vector graphics programs such as AutoCAD™ do not work well for laser display use. This necessitates laser-specific computer software. Current laser-scanning techniques are introduced in this article, which emphasizes the limitations of scanner technology and suggests remedies. Considerations for the design of laser graphics software are then set forth, and current laser systems are discussed, with an in-depth example using software developed by the authors. Future directions for laser display, scanning technology, and software are also reviewed.

Projected laser displays are by now commonplace. They are seen in applications such as planetarium shows, amusement parks, discos and nightclubs, and special events. There are four main elements used in laser displays:

• Beam effects. Still or moving beams are seen in midair, usually in combination with smoke.

• Interference effects, or lumia. The laser beam passes through a distorting medium such as textured glass, producing soft, gauze-like effects.

• Abstract graphics. The beam bounces off moving mirrors. The simplest system uses mirrors attached to loudspeakers for direct music visualization. More advanced systems use mirrors on galvanometer scanners, driven by oscillators to create abstract Lissajous (spirograph) patterns.

• Representational graphics. Mirrors on scanners are moved under computer control to create drawings, logos, text, and other random-scan vector images. Because they are vector, the graphics are cartoon-like outlines or simple wireframes, with no area fill.

Because this article is primarily concerned with representational graphics, the term "graphics," as used throughout, refers to this most complex type of laser-projected display.

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The requirements for a laser graphics display are conceptually simple: a laser producing visible light, a projector that scans the laser beam in horizontal and vertical directions, and a computer or similar system to drive the laser scanners:

• The laser. Display lasers usually are filled with a gas containing helium, neon, argon, or krypton in various amounts. These are available in a variety of beam colors and output powers. For the purposes of this article, the laser is merely a light source enabling graphics to be viewed.

• The projector. This contains scanners and the color system — everything except the laser and signal source. Typically, a multicolor beam (e.g., containing red, green, and blue wavelengths) goes through a color-selection device. The resulting beam passes through a shutter, used for safety and aesthetic reasons in case the color device cannot fully extinguish the light. The beam finally is moved horizontally and vertically using X-Y scanners. Figures 1-6 show different types of color laser projectors.

• X-Y scanners. Laser projectors are based around a pair of galvanometer scanners. A tiny mirror, typically 5x8 mm, is attached to each scanner's shaft. The scanners are positioned so the laser's beam first strikes one mirror, which scans horizontally, then strikes the other mirror, which scans vertically, and finally travels to the display screen. This combination of X and Y scanning makes possible random-scan vector drawings.

Until recently X-Y scanner technology has been surprisingly uniform throughout the professional laser display industry. Most graphics systems use closed-loop moving-iron scanners from General Scanning Inc., usually model G-120. Some low-cost systems use open-loop scanners from the same company, usually model G-124. Although many laser show companies wanted improved scanner technology, the ubiquitous GSI products had a beneficial effect: they were one of the few *de facto* standards in the laser industry.

Recently, scanners and scanner amplifiers from Cambridge Technology Inc. have become available. These appear to give a performance improvement of 1.5 to 3 times that of G-120 scanners, depending on which scanner amplifier is used with the G-120. An industry group is attempting to define speed standards; one for older G-120 type technology and another for faster scanners such as those from Cambridge.

• Scanner amplifiers. These condition and amplify the drive signal for the scanners. The better they do this, the better the resulting graphics.

Closed-loop amps use a feedback technique to tightly control corresponding closed-loop scanners. Open-loop amps have no direct feedback link to open-loop scanners. Techniques sensing back-EMF (electromotive force), caused by the scanner's resistance to movement, can synthesize feedback and partially compensate for this deficiency.

There are many different sources for scanner amps — almost one for each laser show company. Unlike the situation with lasers and scanners, a display system designer can significantly improve system performance by his or her choice of scanner amplifiers.

• Blanking. One important function of a projector is to blank the beam, or turn it on and off. This allows discontinuous graphics to be drawn — traces connecting different parts of the image cannot be seen. Blanking control is usually handled as a subset of intensity and/or color control. For example, all colors go to zero when blanked points are being output.

• Intensity and color. Many different ways have been developed to control intensity and color in a laser projector. The most common today are scanner based, where a scanner moves or chops a beam, and acousto-optic modulator (AOM) based, where a special crystal optically diffracts a beam based on a driver signal.

The intensity and color subsystem is probably the key area distinguishing different projectors. The talent of a display system designer is most rigorously tested here.

Unfortunately, the many methods of controlling intensity and color make it difficult for the laser graphics software designer. In the past, software was designed to support one or a few types of devices. Recently, more systems have developed "universal" outputs that can run any type of intensity and color devices.

• Other projector components. There may be many other devices in the projector, such as solonoid-activated mirror positions for creating beam and lumia effects. These do not require sophisticated computer controls and therefore will not be further discussed here.

• Laser graphics drivers. Representational graphics are almost always digitally created. A computer outputs a series of voltages designed to control the X and Y scanners and the intensity/color devices. These voltages can directly drive the laser projector, or can be encoded on tape using frequency modulation or pulse-code modulation techniques for later playback. (The voltages cannot be recorded using standard tape recorders as they often contain unrecordable direct current [offset] voltages.)

The preceding has been a necessarily brief overview of laser display systems. Two more detailed discussions of this technology are a 1982 paper by Ken Deaton[1] and a 1991 article by Ivan Dryer.[2]

Vector Images for Lasers

Any description of laser graphics has to take into account the special requirements of these vector images. These include the differences between laser vector graphics and raster graphics, and the limitations of laser-projected vectors. (Strictly speaking, "vector" implies polar coordinates such as those seen on a vectorscope used to monitor television signals. The term "vector" will be used here in the broader sense of specifying only endpoints of a line — whether in polar or Cartesian coordinates — as opposed to specifying every pixel in a line to be drawn, e.g., raster.)

Laser Graphics vs. Raster Graphics

Laser displays are almost always done using vector computer graphics. The primary reason is that vector graphics provide brighter images than raster graphics, for any given laser source. Although display lasers are extremely bright, their light is concentrated in one small area — total optical power ranges from 0.02 to just 20 W. Instead of enlarging 20 W of light to fill a screen, and then only turning on desired parts (pixels), the vector technique allows maximum brightness, as only the drawing itself is imaged.

Unfortunately, laser beams are difficult to steer. Unlike electron beams in cathode ray tubes (CRTs), laser beams are made of uncharged photons. They do not respond to magnetic fields, so brute-force methods are necessary. As described earlier, galvanometer scanners with tiny mirrors are almost universally used for X-Y deflection.

This introduces the problem of controlling these moving mirrors. The scanner shaft and mirror have enough mass to possess significant inertia. This limits random-access vector drawing to a useful bandwidth of less than 2,000 Hz.

It should be noted that raster laser projectors have been successfully operated, generally using rotating polygonal mirrors for high-speed horizontal scanning and fixed-frequency galvanometer scanners for medium-speed vertical scanning. Once such a device is constructed, the input to it is essentially the same as to a projection CRT, and thus need not be further discussed here.

Laser Display Advantages

Much of this paper is devoted to limitations of laser display. In fairness, we should mention four significant advantages that make laser displays a viable and desirable medium. First, they can project very large images. This is used in shows that scan onto such "screens" as Stone Mountain in Georgia, Grand Coulee Dam in Washington State, and Niagara Falls. Second, the pure, highly saturated colors of laser light glow with an eerie shimmering. This "laser speckle" is due to optical effects of the laser's coherent light that actually occur on the retina, making the light literally eye-catching. Third, the contrast ratio is extremely high (over 100:1) — images seem to float when seen in a dark environment such as a planetarium dome. Fourth, nongraphics effects such as large Lissajous patterns, wispy lumia, and city-spanning laser beams are difficult to achieve with other media or techniques.

Laser Display Limitations

One branch of computer graphics uses oscilloscope-type CRTs for displaying vector graphics, in applications such as computer-aided design (CAD), flight simulation, and arcade video games (two well-known examples are Atari's *Asteroids* and *Battlezone* games from the early 1980s). In a CRT-based system, the computer simply specifies the vector endpoints. Hardware circuits manage the stroke, evening out the vector drawing speed. This is not usually done with laser projectors.

Laser vectors cannot be stroked nearly as fast as CRT vectors. For example, laser graphics must dwell around 300 msec at corners and at stroke endpoints, to avoid overshoot and ringing. The dwell time is usually added not in the projector hardware, but by adding extra points into the image.[3] In other words, the software manages the stroke, attempting to achieve constant velocity.

A typical line might have 22 points: at the line start location there will be 5 blanked, then 3 visible "anchor" points; 6 points along the line, and at the end location another 3 visible and 5 blanked. With high-performance scanner amps, the same line could be improved to about 13 points.

This means that a large number of points are used simply for velocity compensation. Compounding this problem, the laser-projected image fades faster than the same image drawn on a CRT. This is because the laser cannot rely on phosphor persistence — only on the eye's natural persistence of vision. Only about 700 discrete points can be drawn before the image begins to flicker objectionably. ("Objectionable" is a relative term; in the authors' experience, many laser artists are less bothered by flicker than are audience members.)

The result is that lasers cannot do detailed AutoCAD-style vector drawings. The number of vectors in a low-flicker image is on the order of 50 or less. This is why 2-D laser light show drawings tend to be cartoon-like outlines, and 3-D objects are almost always wireframes.

Because of these laser display limitations, common computer graphics programs such as AutoCAD are not well suited for laser drawing tasks. One major laser display company tried using a commercial computer-aided design (CAD) program for creating 3-D objects. They then converted the data for laser use. The main problem found was in vector sorting. For complex objects, vectors were drawn in a haphazard order, which significantly slowed the effective scan speed. This and other problems were intractable enough that the company is considering moving back to laser-specific drawing software in its next-generation design.[4]

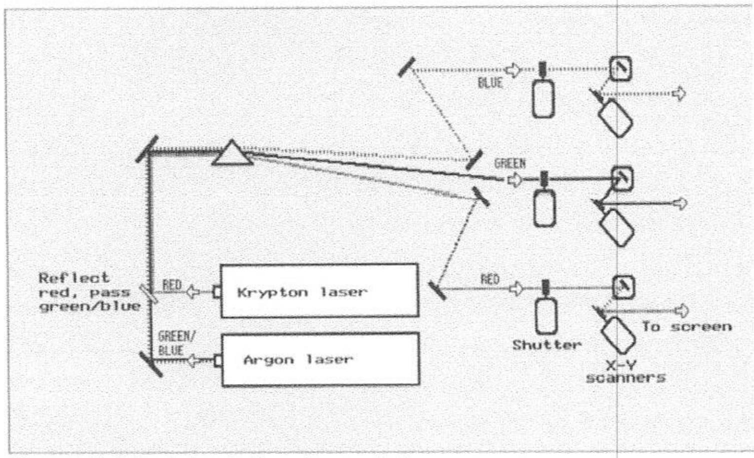


Figure 2. Multiple single-color beam laser projector.

Advances in Display Laser Technology

These limitations have bedeviled laser system designers ever since the scanning technique was developed in the mid-1970s by Ivan Dryer of Laser Images Inc. for the first Laserium™ shows. To achieve higher graphics performance, Dryer and others gradually moved away from open-loop scanners to the more expensive but more controllable closed-loop technology. Today, nearly all professional graphics projectors use closed-loop scanners.

In the past half decade, there have been at least three major advances in laser display technology. The first is improved lasers, especially designed for the needs of laser projectors. The second is intra-image color via mixing of red, green, and blue beams in a manner analogous to RGB mixing in television. The third change has been increasing sophistication in computer graphics software applied specifically for laser vector drawings.

These changes had a synergistic effect on each other. New-generation mixed-gas lasers have made it possible to get a good balance of red, green, and blue light from a single laser. New-generation software was able to output red, green, and blue signals on a point-by-point basis. These helped speed the introduction of projectors capable of producing a full-color image. (Full-color is another relative term. Due to limitations in available laser wavelengths, most RGB systems' color gamut is weak in red and blue, resulting in a somewhat restricted choice of colors.)

The improvement in computer graphics for lasers, of course, was not limited to RGB capability. Features such as 3-D data bases and graphic user interfaces (GUIs) are now standard for laser computer graphics. But before looking at current systems, we will first examine elements unique to the design of laser graphics software.

Considerations for Laser Graphics Software

Background

A laser graphic is essentially a connect-the-dots drawing. A typical frame is made up of 300 to 1500 points. At minimum each point has an X and Y spatial coordinate and a color coordinate. In simple systems, the color is either draw (pen down) or blank (pen up). More advanced systems use lookup tables for the color, while the most advanced store the actual red, green, and blue values for each point. Systems using three-dimensional calculations include a Z spatial coordinate. Pangolin is developing a system which also adds an F, or focus coordinate, to control the beam size at each point.[5]

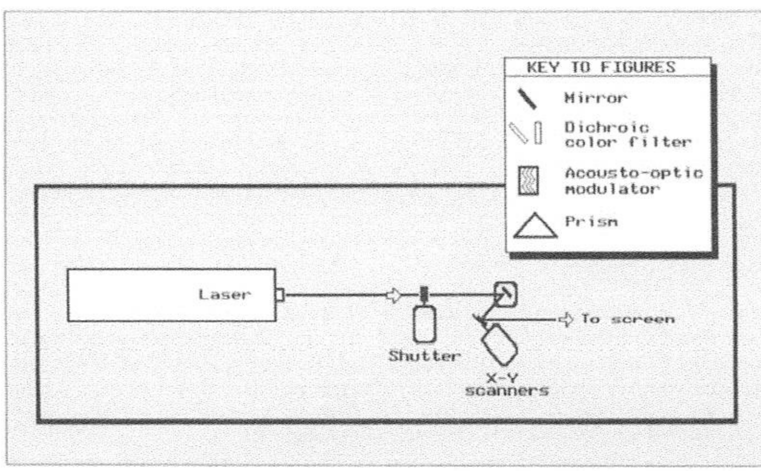


Figure 1. Single-color laser projector.

Spatial Resolution

Commonly, the X, Y, and Z coordinates are stored in resolutions of 8, 12, or 16 bits each. Given the natural smoothing action of the scanning technique (one of the few benefits of the scan mirrors' high inertia), the visible limit of resolution is approximately 10 bits. That is to say, the eye has difficulty perceiving any difference between frames and animations shown at 10 bits versus higher resolution.[6]

Eight-bit spatial resolution, while noticeable, is sufficient for low-cost applications, especially those where laser graphics are not the primary focus of attention (e.g., discos). In higher-resolution systems, the choice between 12 and 16 bits depends on the software design. For example, if image data is post-processed in the computer to produce digital rotations, translations, etc., then 16 bits may be preferred to avoid any possible computation rounding errors.

Intensity Control

Since most laser projectors use the same type of scanning devices, there is not much variability between systems in terms of how X, Y, and Z coordinates are handled. However, there are a number of different techniques for intensity and color control. In fact, intensity is often controlled separately from color, multiplying the possibilities. For "universal" laser graphics systems, the designer must provide for as many different devices and techniques as possible.

Here is an example. For intensity control, a projector will have either:

• No intensity device. The beam is always on. It is possible to draw many graphics with few or no visible traces between graphic elements, so this is an option in low-cost systems.

• Digital intensity device. The beam is either on or off. Usually implemented with devices driven by transistor-transistor logic (TTL) level signals.

• Analog intensity device. The beam can be faded in intensity. Usually implemented with devices driven by signals between 0 and 5 V.

The computer graphics system should handle all three possibilities. For example, Pangolin's system provides both a TTL-level digital output and a 0 to 5-V analog output. For systems with no intensity, the computer palette is adjusted so normally invisible blanked lines are drawn in a visible color. These accommodations are easy to implement.

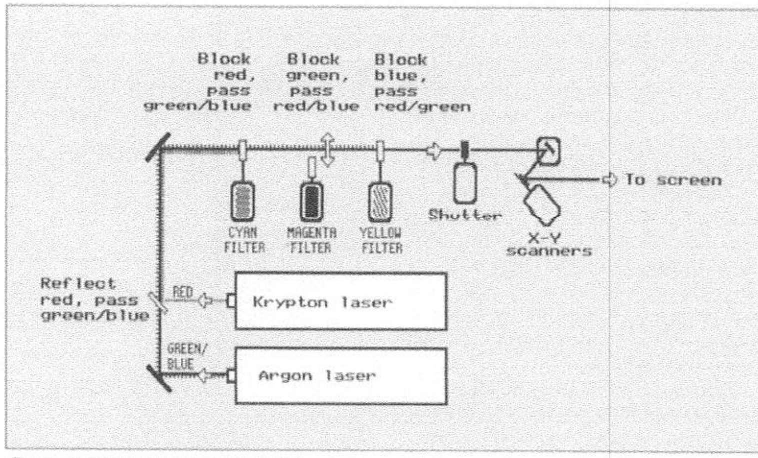


Figure 3. Digital color laser projector.

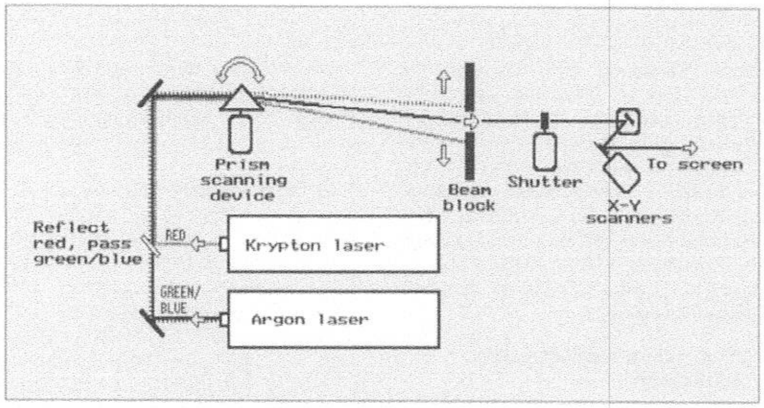


Figure 4. Single-channel analog "prism" color laser projector.

However, to truly complicate matters, intensity devices vary in speed. If an acousto-optic modulator is used, it operates much faster than the associated X-Y scanners. This means that a command to turn the beam off at a certain point will take effect before the beam reaches that location. Few systems have hardware compensation for this time difference, so the adjustment is usually done via software.[7]

If a graphics system is designed for a specific projector, the desired lag or lead time can be hard-coded into the software. However, systems designed to work with any projector must have variable lag/lead times. This is usually expressed as a point offset, meaning when the command to move to a certain point is given, the intensity is picked up from previous or subsequent points.

Color Control

The previous discussion concentrated on intensity devices. These devices are also used in color laser projectors. Now the designer's job is further complicated because there may be a single color signal sweeping across the visual spectrum, or three color signals, one each for red, green, and blue. (One company even markets a projector requiring two color signals, red and green/blue.)

Most color projectors use the color device for overall intensity control. However, a few have a separate intensity device that works on the final, mixed color beam. For these systems, there will have to be separate signals and separate point offsets for intensity and color.

The following is a brief discussion of the major types of color laser projectors (Figs. 1-6). Note that although the figures show a pair of lasers used as input, the input can vary from one multiwavelength mixed-gas laser to three separate lasers, one each for red, green, and blue.

• Single color (Fig. 1). The laser's output color is the only one used.

• Multiple single-color beams (Fig. 2). This is the technique used in older "Laserium-style" shows. There are two to four sets of scanners, each one of which has a single color beam as input. Usually it is also possible to scan through the colors, so each image is multicolored, as a special effect. Unless the scanning technique can be random-access controlled, intra-image color is not possible — each graphic is a single color.

• Digital color (Fig. 3). A beam containing multiple colors is intercepted by dichroic color filters — usually cyan, magenta, and yellow. By various combinations of the filters, one of seven different colors is selected (plus black, or no color). Normally this method does not allow intra-image color, as the filter-moving devices are relatively slow. An alternative implementation splits the beam into red, green, and blue components, uses a digital intensity control to turn each one on or off, and then recombines them.

• Single-channel analog (prism) color (Fig. 4). A beam containing multiple colors is sent through a prism, or diffraction grating mounted to a scanner. Movement of the prism selects colors. Scan speed is high enough to provide intra-image color. However, the software should implement techniques to avoid unwanted color trails. These occur at the ends of lines as the prism scans across colors until reaching the final blanked position.

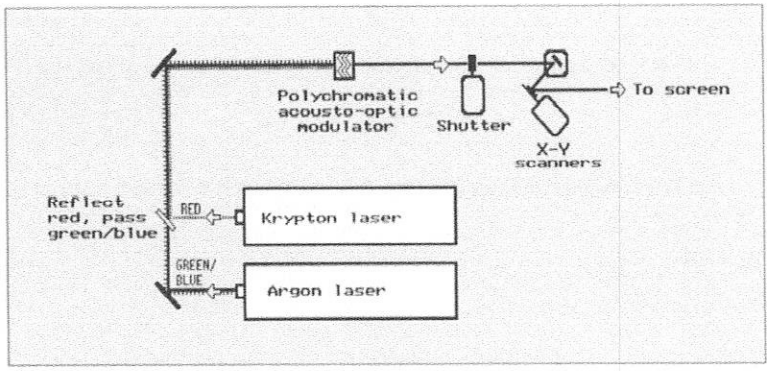


Figure 6. Multiple-channel analog color laser projector.

• Three-channel analog (RGB) color (Fig. 5). A beam containing multiple colors is split into red, green, and blue components. Each beam is controlled by an analog intensity device, usually either scanner-based or an acousto-optic modulator (AOM). The beams are then recombined. The number of possible colors depends on the intensity resolution. For example, if there are 8 bits (256 levels) per device, the result is 24-bit (16.7 million levels) color resolution. The RGB technique is designed specifically to handle intra-image color.

• Multiple-channel analog color (Fig. 6). Instead of controlling just three wavelength regions (red, green, and blue), additional wavelengths are controlled individually. This works because multiline lasers can have as many as 20 discrete wavelengths. This technique uses recently developed polychromatic acousto-optic modulators (PCAOM). By using special driver circuitry, a single PCAOM crystal can simultaneously control the intensity of multiple wavelengths (colors). No existing software has the capability to control more than three color channels, but future multiple-channel systems are under development. As with RGB, the PCAOM technique allows for intra-image color so different parts of a single image are drawn in different colors. Because PCAOMs are easy to set up and maintain, and give good power throughput and beam quality, they have become the method of choice for intra-image color.

This discussion of intensity and color has been detailed, but it illustrates the importance of making provisions for the special needs of laser projectors.

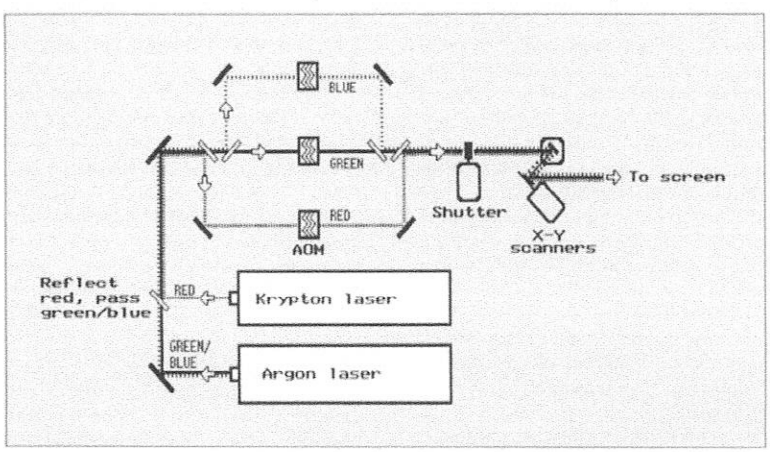


Figure 5. Three-channel analog (RGB) color laser projector.

Objects Disappear, Only Points Remain

One key difference between CRT-based and laser-based vector graphics is in the point lists. As described earlier, in CRT systems usually just the endpoints of each vector are specified by the software. Due to the limitations of scanner projectors, laser software requires additional points to be placed along the vectors, attempting to produce constant beam velocity.

This is an important design consideration. Essentially, it means laser graphics software must be extensively point-oriented, unlike CAD systems, which store objects as primitives (e.g., a square is completely described by the two corner point locations, line

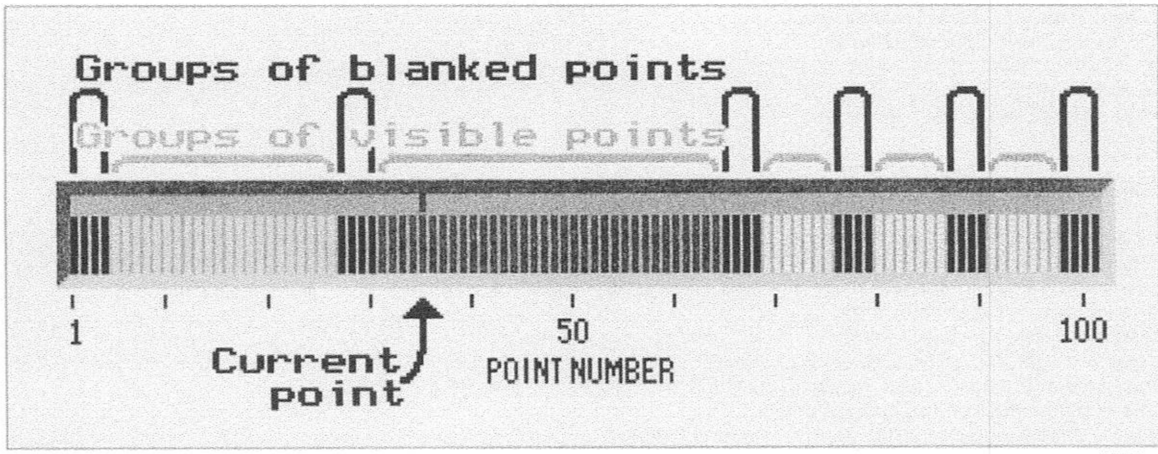


Figure 7. Laser points arranged in time sequence.

thickness, and line color). Once a laser square is drawn, it becomes a series of points. The "idea" of the square disappears, since the square was decomposed into a point list.

A typical square might start with three blanked points, or points where the laser beam is turned off. This gives the scanned beam time to settle after jumping from its last location. Then would come two anchor points — visible points at the same location, also used to help settle the beam and to sharply define the square's corner. Each side is drawn with mid-stroke points to help achieve constant scan velocity. At corners, there will be additional anchor points to allow the scanners time to settle before changing direction. Finally, the last points in the square are anchor points, again followed by a few blank points.

The point-oriented approach means the software should have provisions for automatically creating blanked, anchor, and mid-stroke points when drawing primitives. Also, the software should have extensive tools for editing individual points and groups of points. This allows the user to override any automatic point placement (such as having too few or too many blanked or anchor points), in order to get best results for his or her projector.

Since a laser graphic is a connect-the-dots drawing, the order in which dots are drawn is important. A system should display this order, to help the artist control how the graphic is drawn.

In Pangolin's system, a laser graphic is simultaneously shown in two very different views. One shows the points' spatial location — the traditional 2-D view. Each point's X and Y coordinate is plotted using the point's appropriate color. The other view shows a time sequence — like a timeline (Fig. 7).

In this view, every point is represented as a colored vertical bar. The color indicates the point's laser-projected color. For example, blanked points show up as a black zone; the more points, the wider the zone. The figure shows groups of visible points that make up each "object," such as a line, square, or circle. (Recall that objects *per se* are not stored, only their constituent points.) Each stroke begins and ends with blanked points, allowing the beam time to settle. The currently selected point is highlighted by a longer vertical bar. As the user moves a slider, this bar also moves.

This view allows the user to see groups of like points, making it easier to distinguish, for example, an object drawn in red from one drawn in blue. Points can then be quickly selected or deselected for editing purposes. More importantly, it shows the user the sequence in which the graphic will be drawn. This information can help get the best results out of the scanner's limited bandwidth, as the beam travel can be adjusted for minimum distance.

These considerations — spatial resolution, intensity and color control, and point orientation — are added to others such as computer platform, digital-to-analog board design, and software usability features. The result is a unique laser graphics system. A conservative count is that there are at least 20 different major laser software programs presently in use worldwide. (This counts only different design approaches, not variations within a software family.)

Let us now turn to the current state of laser computer graphics. We will then take a detailed look at the authors' system as an example.

Current Laser Display Computer Graphics

The State of the Art

To those working in traditional raster computer graphics, current laser display systems may seem antiquated. For example, 3-D systems became widespread only in the last half of the 1980s, and such standard features as cut-and-paste and graphic user interfaces (GUI) appeared only since 1990. The authors' opinion is that laser software tends to remain at least five years behind raster graphics software.

Why is this? It is a combination of laser display limitations and the nature of the laser industry. The first reason, display limitations, has already been discussed. When the best available output is cartoon-like drawings or wireframe images, there is no need to support advanced techniques such as texture mapping or ray tracing.

Nature of the Laser Industry

The second reason why laser graphics has lagged behind raster graphics is that laser companies are not well equipped for this work. This

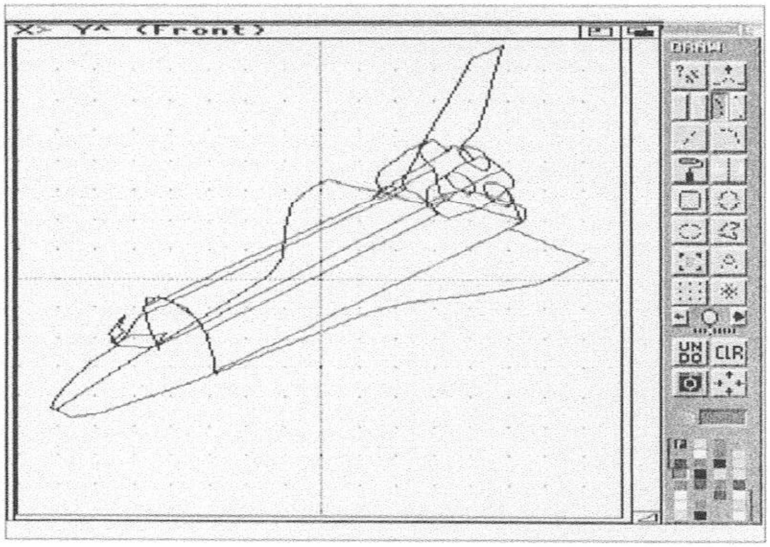


Figure 8. Drawing screen of laser software.

is not a negative statement; many companies have done excellent work given their resources.

However, the laser entertainment field is neither lucrative nor cutting edge. Most larger companies do all aspects of production themselves, from designing projectors to writing software and producing shows. Government grants and university-sponsored research are practically nonexistent.

Because companies are overworked and underfunded, the impetus to develop easy-to-use, commercial-quality software was never strong. As in the early days of commercial computer graphics, each company had its own preferred system, which was adapted and improved on an ad hoc basis, depending on the effects needed for a particular job. And, unlike early raster graphics companies, software was not at the core of laser display, but was only one part along with lasers, projectors, abstract graphics, beams, and lumia.

This situation may be changing. A trade organization, the International Laser Display Association[8] (ILDA), was founded in 1986. ILDA has helped standardize file formats for image transfer and electrical standards for projector connections. Such developments have broken some of the "not invented here" syndrome that kept laser companies as generalists. With greater cooperation and specialization came improvements in many areas, including computer graphics.

An early pioneer was the LGRASS system developed by Stephen Heminover of Aura Technologies. It built on the earlier CRT-based GRASS (GRAphics Symbiosis System) of Tom DeFanti of the University of Illinois, Chicago. Other notable nonproprietary systems were developed by John Tilp, Dann Sanner, and Gregg Weissman at Laser Images Inc., and John Clouse, Bob Mueller, and Jim Arledge of Laser Fantasy International. All have been improved over the years and are currently available. The remainder of this article describes the system developed by the authors.

An Advanced 3-D Laser Software System

Pangolin's Lasershow Designer is an advanced 3-D laser software system that illustrates one solution to the special requirements of laser displays. The software is divided into two main parts.

The first is an assembly language core of graphics primitives. These perform tasks such as reading and writing points, displaying frames, and setting 3-D parameters. Although some of these provide operating-system-like functions (laser file handling, port I/O) to the end user, they all are accessed as single commands and thus function in effect as primitives.

The second part is the graphic user interface (GUI). It is essentially a 3-D CAD program written solely for laser usage. It relies on the primitives for basic operations, while additionally providing many higher-level functions. Figure 8 shows the drawing portion of the GUI.

Core Primitives

The core primitives are optimized for real-time 3-D display of the points in a frame. Since all points have the same scaling, rotation, translation, and 3-D perspective transforms applied, matrix multiplication techniques are used to reduce calculations to a minimum.

Running on a 25-MHz 68030-based computer, the system processes 200,000 points/sec in 2-D mode, or 30,000 points/sec when 3-D perspective transforms are added. For a 500-point frame, the latter figure corresponds to 60 frames/sec. This is more than adequate. Due to scanner limitations, typical laser frame rates are usually much lower, in the 10 to 20 frame/sec region.

The core primitives can be accessed through any standard computer language (Table 1). The matrix technique leaves more than enough time for the host language to perform laser displays in real time. This has advantages over the older technique of precomputing all frames. For example, a single frame plus a simple loop can display a 3-D rotation that might otherwise require 360 separate precomputed frames. In pseudocode the procedure for a Y-axis rotation looks like this:

```
DisplayFrame(1)
FOR angle=0 TO 360
        DisplayAngle(0,angle,0)
        DisplayUpdate
NEXT
```

Real-time display also has advantages over using audio or videotape to record precomputed sequences. Often, the encoding techniques necessary for tape introduce distortion or jitter. FM flutter is eliminated when the computer outputs the show in real time.

Laser-show scripts are created using the computer language plus the core primitives. The disadvantage of this technique is that the user must write a program in order to set up a show. The advantage is that anything the computer can do can also be done with lasers.

Table 1 — Selected Core Primitives (All are accessed as single commands)

Drawing/Editing
Read and write a point's XYZ and color coordinates
Insert and delete a point or group of points
Draw a laser vector (given previously set parameters for blanking and anchor points, and mid-stroke point spacing)
Copy and delete a frame or group of frames
Real-Time Display
Display a frame
Assign a frame to one of 32 tracks (enabling multitrack output of up to 32 objects)
Enable selected graphics operations: translation, clipping, rotation, scaling, 3-D perspective (the fewer operations enabled, the faster frames can be calculated)
Set overall output size (signal level for XYZ and color channels)
Set point output rate (scan frequency)
Set first and last points to be displayed (to show only parts of a frame)
Set point offset (to adjust for different intensity and color devices)
Set graphics parameters: scaling, pre-rotation translation, local rotation angle, local rotation centerpoint, post-rotation translation, world rotation angle, observer viewpoint, distance to viewplane
Set window (viewport) size and location
Attach one frame to follow the path of another
General
Load and save laser file (supports different formats)
Load and save computer and laser palettes
Various SMPTE time code commands
Various input/output port commands

For example, Pangolin has developed a joystick-controlled game similar to the classic Atari video game, *Asteroids*. The motion of the spaceship, targets, and bullets are all computed in real time and displayed by the laser. The authors believe that this is the first real-time interactive laser video game.

Intensity and Color Control

The provisions a designer must make in the areas of intensity and color control have been discussed at length. We will now describe how these considerations were implemented in this system.

For digital on/off blanking (Fig. 1), there is a TTL-level signal that goes low when a blanked point is output. This signal is also used in any systems that control blanking separately from color. (The signal comes in two "flavors" — blanked and visible. One is TTL high during blanking, the other is the invert, TTL low.)

For both analog and digital RGB color (Figs. 3, 5, and 6), there are three analog 0 to 5-V outputs, one each for red, green, and blue devices. These outputs drive both analog and TTL-level drivers.

For single-color analog intensity (Fig. 1, with an intensity device instead of a shutter), only one of these signals is used. For prism color systems (Fig. 4), again only one of the RGB signals is used.

For multiple single-color (Fig. 2), additional hardware cards are used. Each one drives its own set of scanners and intensity/color devices. Up to four can be installed in a single computer.

For multiple-channel analog (Fig. 6), three channels — red, green, and blue, naturally — can be controlled. Future systems will be able to control up to six channels, to more accurately blend different wavelengths.

The blanking and color signals can be independently advanced or retarded to compensate for the speed of the projectors' devices. For example, "color box" projectors with digital color (similar to Fig. 3), have color devices that are slow relative to the blanking device and X-Y scanners.

To support these, Pangolin has two special modes, the most complex of which seeks ahead during blanked periods to find and activate the upcoming color, so the color devices have time to move into position while blanking is still being implemented. With this mode, intra-image color is possible.

Table 2 is reproduced from Pangolin's user manual. It gives an idea of how a simple need — controlling beam intensity and color — can become a fairly complex task for the system designer. Fortunately, the software makes this easy for the end user. It only takes about two minutes to change from one type of projector to a completely new one.

Special Laser Considerations

The system designer should go beyond merely supporting laser's special needs. Ideally, operations should be implemented in the most efficient or useful way possible. For example, a common special effect is a write-out, often used when projecting signatures or drawings. The graphic is progressively revealed, as if drawn by an unseen hand.

This effect is frequently implemented in older systems simply by incrementing the frame's point display list. The first point is shown, then the first two points, then the first three, and so forth. However, this is difficult for the scanners, when they are initially drawing only a few points. This also makes the write-out slow down in an exponential fashion as each subsequent point is added.

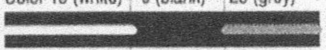
Pangolin's assembly-language core uses a different technique. The entire frame is always scanned. At first all points are temporarily blanked. Gradually, points are made visible (except, of course, for those intended to be permanently blanked) until the entire frame is revealed. The visual effect is a smooth, linear reveal.

Other techniques such as clipping are also optimized for laser display. In Pangolin's system, points that fall outside the viewing region continue to be scanned, but they are blanked (rather than being dropped from the display list). This is done to keep the scan rate constant for any given frame.

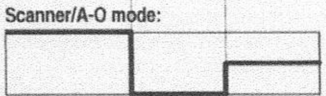
Table 2 — How Color Signals are Generated to Support Different Hardware Devices

Color of points being output:

Color 15 (white)	0 (blank)	25 (grey)

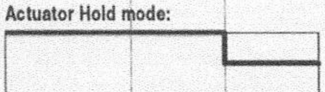


Scanner/A-O mode:



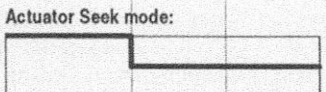
	Color 15 (white)	0 (blank)	25 (grey)
R:	255	0	127
G:	255	0	127
B:	255	0	127
Blank bit:	0	1	0
Visible bit:	1	0	1

Actuator Hold mode:



	Color 15 (white)	0 (blank)	25 (grey)
R:	255	255	127
G:	255	255	127
B:	255	255	127
Blank bit:	0	1	0
Visible bit:	1	0	1

Actuator Seek mode:



	Color 15 (white)	0 (blank)	25 (grey)
R:	255	127	127
G:	255	127	127
B:	255	127	127
Blank bit:	0	1	0
Visible bit:	1	0	1

This chart shows a plot of the R, G and B voltages for each of the three color hardware modes. During blanking, the voltage drops to zero in Scanner/A-O mode, stays at the last output in Actuator Hold mode, and seeks ahead to the next output in Actuator Seek mode. The blanking and visible bits are unaffected by the mode setting.

Subtle considerations such as these are one reason why the authors believe a laser graphics display must be designed from the ground up around the restrictions imposed by laser scanners.

Future Directions

Laser display is primarily limited by the projection apparatus — most specifically, the galvanometer scanners. Improvements in scanners recently announced by General Scanning Inc. and Cambridge Technology Inc. have doubled the usable resolution. This helps, but still puts laser display far under the information density of either a vector CRT or a raster display.

Other scanning technologies may come into play. Solid-state scanning using acousto-optic crystals was demonstrated in the early 1980s, but the resulting TV-like image has a narrow scan angle.

Nonscanning techniques are further on the horizon. One example is using binary optics or holographic gratings to diffract light. The beam is simply sent through the diffracting medium and an image is projected. However, for the foreseeable future, laser display will still rely on, and be limited by, galvanometer scanning.

Some help can come from improved computer techniques. For example, the display list of scanned points can be broken between scanners. Instead of a single, badly flickering 2,000-point image, four scanner pairs would each display 500 points. The equipment for such parallel processing is expensive, as it requires three additional projectors. However, it may well be the only practical way to display detailed vector drawings with lasers.

Another computer-related advance will be to move the stroke generation task from software to dedicated hardware. Two European laser companies, Lobo and LaserAnimation, have "dynamic interpolation" systems where transputer or digital signal processing chips generate the mid-stroke points necessary to keep scan speed constant. The authors do not know how well these particular implementations operate, but the basic principle is sound. Hardware stroke generation opens the way for object-oriented graphics creation, editing and storage, as opposed to current point-oriented systems.

Most other improvements will be variations on problems already solved in traditional computer graphics. For example, 3-D laser graphics are almost always shown as transparent wireframes. Laser Images Inc. recently demonstrated hidden line removal for convex objects. Laser-specific software with hidden line removal of arbitrarily complex objects is just a matter of development time.

Another obvious area for improvement is in user interface design. At the present time, the best GUIs for lasers are at about a 1989 level. With such a small market, laser user interfaces will never compete with those in commercial drawing software (such as Adobe Illustrator, Corel Draw, etc.), but these commercial programs provide many good ideas that can be adopted for laser use.

Finally, improvements in ancillary equipment will help expand the market for laser graphics. At present, the cost and complexity of a complete projection system deters many potential users. As these devices become more affordable and simpler to operate, there will be a greater incentive to produce powerful, easy-to-use laser graphics software.

Endnotes and References

1. K. Deaton, "Considerations in the Design of a Laser Graphics System," *Proceedings, Graphics Interface'82*. National Computer Graphics Assoc., pp. 381-386.
2. I. Dryer, "Lasers Color Display and Entertainment Applications," *Laser Focus World*, Sept. 1991.

3. Hardware generation of stroked laser vectors is now being done in at least two systems, as described in the "Future Directions" section. Since all other laser systems use software generation of stroke details, the software technique is extensively discussed in this paper.
4. Personal communication, Sept. 1992. The company requests anonymity.
5. The software for focus is trivial. The problem is hardware devices fast enough to do useful intra-image focus. Pangolin has developed a preliminary specification for such devices, in the hopes of avoiding a multiplicity of incompatible techniques. The specs are available upon request from Pangolin.

6. P. Murphy, "Measuring Effective Resolution: How Many Bits are Enough?" *Laser Talk*, Spring 1992. International Laser Display Assoc., Santa Monica, Calif.

7. There are two hardware ways to delay a signal going to an AOM. One method in use is an R-C network. Unfortunately, this slows down not only the signal, but its rise and fall characteristics, losing the advantage of sharp beam on/off edges. The preferred way is with a digital delay, which changes only the signal timing.
8. International Laser Display Assoc., 1126 Ashland Ave., Santa Monica, CA 90405. The standards documents mentioned in the text are available through ILDA's Technical Standards Committee.