COMPUTER ANIMATION AT LAWERENCE LIVERMORE LABORATORY

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In any discipline where the desired results of expended effort can be pictorial in nature, we find computer graphics. In those particular cases where the results can be displayed as a sequence of pictures so as to give the illusion of motion, we find computer animation. The uses of animation made by any discipline are as varied as the disciplines themselves.

At the Lawrence Livermore Laboratory, we have been producing computer animated films for well over 10 years. These films have been used both as a means to aid researchers with their work and as a means to communicate to others the results of their calculations.

Until a few years ago, the only means of direct computer film output was 35mm black and white microfilm. This film was either viewed directly on a 35mm projector or else reduced to 16mm on an in-house optical printer. The use of 35mm proved unsatisfactory for the obvious reason that 35mm projectors are not commonplace like 16mm projectors. Whereas we actually have a 35mm projector at LLL, it was recognized that most other laboratories that we exchange film with will not have a 35mm projector.

The 16mm motion picture film is the most reasonable medium in which to exchange film in the scientific community. The main reason is the abundance of 16mm motion picture film projectors. Also recognize the fact that there is a <u>single</u> standard for 16mm film. It is this standard that allows computer animated films to enjoy the popularity they do.

The production of color computer generated film is a simple extension to the optical reduction process. The user produces a number of 35mm black and white films each corresponding to the particular color desired. These films are then superimposed one upon another onto 16mm color film with the appropriate color filter inserted into the light path. This technique is currently the most popular method for the production of scientific computer animation. The major drawback is the time required to make the film. The users generally expect to see their results soon after running their program. It is for this reason that computer films are more often used to show final results rather than as an alternative to other forms of computer output.

These are however, a few advantages to production of film in this manner. The quality of the finished product is better than by any other technique. This is because high resolution color print film can be used instead of high speed Ektachrome used in most direct color film recorders (described below). There are color print films that have a resolution in excess of 200 line pairs/mm in any color. That contrasts sharply with the 20-50 line pairs/mm obtainable with high speed Ektachrome. This becomes important when we recognize the fact that a high quality film recorder is capable of imaging over 150 line pairs/mm on 16mm film. Thus, it is clear that the indirect approach can potentially produce a far superior product.

A second point is that during the optical reduction, it is possible to use the printer for special effects that are not easily programmed. For example, fades and dissolves can be added for essentially no additional effort. A far better control over color can be expected. If the user is unhappy with the choice of colors, the film can be reprinted with different colors. This involves no additional computer runs.

There is one special effect we have used at Livermore on a number of occasions that provides a result that is not easily accomplished by programming. As a simple example, consider two distorted grids that overlay one another. Let the one to be in front colored red and the one to be in back colored green. Suppose further that these grids move with respect to one another. At all those points that the grids cross the film will show yellow (red + green = yellow). This array of yellow dots gives an undesirable effect that can distract from the information the programmer was trying to convey. It is, in effect, a type of optical noise.

To eliminate this effect by programming means computing all of the intersections of the two grids, breaking the green lines into segments with the proper spaces left for the red lines. This is a very time-consuming process and not a trivial one to be done efficiently.

A far simpler solution is to first make a negative copy of the black and white film that is to be colored red. We call this a negative mask. This film is clear except for the black lines. Now the film to be colored red is printed onto color film with the red filter. After the color film is backed up in the printer, the film to be colored green is printed through the negative red mask. This is accomplished by loading both films into the optical printer with the mask closest to the color print film. The black lines from the negative red mask prevent light from passing through the "green" film at exactly those places where the two cross. Thus, the red lines will be unbroken and appear in front of the green lines. Since the negative red mask was made from the original film to be colored red, there is no registration problem. These techniques are used by Hollywood to insert a scene into a different background.

We also use our optical printer for the production of color stereo movies. The printer is used to place the images side by side as required by the Bolex stereo system we use at LLL. It is clear that the calculation of the stereo pair is only a time-consuming extension to the calculation of a single perspective view. The optical reduction is no more difficult then the 35mm to 16mm reduction. The lack of popularity of color stereo movies in the scientific community is not because of the lack of interest in such film nor the ability to produce them, but rather because of the great difficulty of showing them. Given that we can produce the film, there is the problem of a special lens for projection, poloroid glasses for viewing on a special type screen that is probably not available. In addition there is not a standard for a 16mm stereo format.

The advantages are not all on the side of the optical printing method. A number of installations employ a film recorder with direct color recording capability. The essential differences are in the CRT phospor, lenses, and use of a filter changer.

The white phospor CRT is usually a P4, P24, P48 or other braod band phosphor. What is important is that the CRT be capable of emitting relatively equal amounts of red, green and blue light. The lens must be corrected for this light. Most high quality black and white film recorders employ a P11 phospor and use a lens corrected for the blue light this phosphor emits.

There are two systems for generation of color film. The first is called additive color and is generally implemented with a filter changer that consists of a single disk containing at least a red, green and blue filter.

It is clear that any color can be generated by the proper combination of red, green and blue light. However only three colors; namely, red, green and blue can be generated by a single exposure. Generation of the secondary colors require two exposures for each element to be colored, with other colors requiring up to three exposures. For the reproduction of continuous tone images, this triple exposure per element is required in any case and a color disk is generally satisfactory. Here each image is recorded sequentially and only three filter changes are required per frame. However where the computer film consists of colored lines and points, the color disk has some serious disadvantages.

The major drawback is the multiple exposures required for all but the primary colors. If we choose to minimize the filter change time (between 100-250 ms for most disks), this requires processing the data three times to compute the red, green and blue component. The drift in the CRT deflection system will cause some mis-registration resulting in a loss of resolution which is very noticeable in pictures consisting of many fine lines.

If we choose to avoid the drift by changing the filter for each element as required, then the time to generate a frame becomes excessive.

The second system used by film recorders consists of movable arms attached to rotary solenoids or stepping motors. These arms are arranged so that more than one filter at a time can be inserted into the optical path. This allows the use of subtractive color. The advantage here is that seven colors (white, red, green, blue, yellow, cyan, magenta) can be produced without the need for multiple exposures. For pictures that contain a collection of colored lines and characters, this can be a timesaving device. We have found that five or six colors is generally sufficient for most of our work. The loss in resolution due to more than one filter in the optical path is more than made up for by the poor resolution inherent in high speed Ektachrome.

The major advantage of the direct color recording systems is one of fast turn around time. After the film is recorded and processed, the user has a color film. Even with our in-house optical printer, a color film is at least 24 hours away (more typical is one week). The quick turn around time means color film can be used as another form of output and for many users, this far outweighs the advantage of added quality obtainable by the indirect procedure.

There is, on the horizon, a new technique that promises us the best of both worlds. The technique is direct color recording using lasers. The laser has enough light output to directly expose slow speed high resolution color print film. Use of HeNe, Argon, HeCd give red, green and blue light sources eliminating the need for filters. Lasers can be focused down to spot sizes less than 1 micron. This compares to a minimum of 20 microns on a white phospor CRT and can provide all the resolution the color print film can handle.

The color laser film recorder is in some sense, a far simpler device than the color CRT film recorder. The three laser beams are passed through intensity modulators and folded into a single optical path. Using the modulators, the three lasers can produce a light beam of any color. There is no need for multiple exposures.

A color laser recorder has been built by CBS and is operating in a production environment at their studio in New York City. It was designed to transfer videotape to film and is therefore adjusted to record approximately 500 lines on 16 or 35mm film in real time (30 frames per second).

This particular recorder is capable of over 1000 lines resolution. Because of the real time recording requirement, the device becomes bandwidth limited before it is resolution limited. If one were to slow the frame rate down, CBS assures us resolution of 4000 pixels presents no major problem. Our only problem would be in computing all those points.

The laser recorder has the fundamental advantage in that it is much faster than a comparable CRT system. There is apparently no problem in building a machine that can record colored spots with varying intensity at a rate exceeding 7.5 million points per second. This is two orders of magnitude faster than conventional high resolution color film recorders.

The major drawback to Laser recording today is deflection of the Laser beam. The CBS system solves the problem by deflecting the beam horizontally with a rotating minor and vertically with a galvanometer. This works well for videotape but leaves much to be desired for most computer generated data. Forcing the data to be organized in a raster means that vector and character data must be scan converted to a raster format. This means either special purpose hardware or time-consuming software. In addition, there is the problem of "jaggies."

When a vector is broken into a string of points on a finite raster, there will be dis-continuities. For a still picture, this may or may not be objectionable. For movies, the discontinuities along the line move and appear as stair steps moving along the lines and are extremely distracting. This is another form of optical noise.

These effects can be suppressed in several ways. The most straightforward approach is to use a raster finer than the resolution of the film. The only problem is increased computation and storage costs which rise as the square of the raster. We have found that for black and white 16mm microfilm, a raster of 4096 x 4096 is required to remove the "jaggies".

A second technique that has been used requires a recorder with gray scale capability. The screen is considered to be a grid that is intersected by a straight line. Each cell that the line passes through is assigned an intensity propor-tional to the area subtended by the line. More sophisticated approaches take into account slope and adjacent cells. This produces a smooth appearing line. However, the line appears thicker and hence, resolution is reduced.

RCA, among others, is developing a solid state deflector for laser beams based upon a TeO_2 crystal. The amount of deflection is small but can be opticly amplified. Current crystals have a resolution of 512 points which is not enough for high quality film. Deflectors with 2048 point resolution are operating in a laboratory environment and will be available soon.

The solid state deflector has the obvious advantages over a rotating mirror deflector. A recorder built with these crystals will neces-sarily be more a complex device. This is due in the main to the fact that the deflection is a function of the wavelength of the incident light. We believe that these problems can be solved and a high quality color laser recorder will be built soon: Its only a matter of money. We believe that the color laser film recorder will provide a quantum jump in the production and quality of color computer generated film.

LLL is now in the process of building a complete system for the generation of color computer generated film. The objectives were to provide the user both fast turn around time and high quality color film output. Since a color laser recorder was not within our budget, a dual system has been designed. It will consist of a high quality direct color film recorder and a video subsystem. The film recorder will use the subtractive color technique to provide for seven separate colors without the need for multiple exposure. It will be fast enough to record a 200 x 200 grid composed of 40,000 short vectors in less then 10 seconds. It will also be capable of recording continuous tone type images with up to 4096 x 4096 points. We have found however, that 1024 x 1024 is more then adequate for any computer movies we have made. In addition, since the device will not record on print film, we end up resolution limited by the Ektachrome film. The resolution on the CRT will be at least 1500 line pairs across the image area.

The major limitation to quality is the film itself. We expect to use the high resolution capability of the CRT with large format film such as 70mm or 4" x 5". We have found in talking to users and vendors, a lack of under-standing of the interplay of CRT phospher, lens design and film response. We were advised by a vendor that if we purchased their color recorder we would be undertaking a large in-house R and D project just to learn to use it.

A major concern was the elapsed time from running the program until the film was processed. For movies, the major portion of that time is the recording itself. For continuous tone, three color 1024 x 1024 pictures, at least 30 seconds recording time will be required for each frame. That comes out to 12 hours per minute of film. We felt that a good preview capability was essential to prevent recording film generated by a program with a bug. Note that a laser recorder could record the same film in real time.

The video subsystem is designed to preview movies before committing them to film. It is attached to the same minicomputer as the film recorder. The primary element is a video disk such as those used by the television networks for the instant replay. It will have at least three independent channels each capable of recording 300 frames. The three channels can be used to record an RGB picture to be viewed on an RGB monitor for the highest quality pictures. This allows us to look at a movie 10 seconds at a time. We can select frames at random for checking or certain whole sequences to examine timing.

If it is required to look at a longer sequence, we can encode the RGB picture into NTSC format and record it on videotape. In order to do this with standard television equipment means the picture can contain only 480 scan lines instead of the expected 512. The commercially available digital color television systems use a 512 x 512 picture which is <u>not</u> compatible with standard television. It cannot be encoded and recorded with standard television equipment. We have given up those mystical 32 lines for the sake of compatibility. There are many people here who would willingly trade the ability to record their material in color for those 32 lines. Some habits are just hard to break.

It is important to note that the NTSC recording does not have the resolution of the RGB image. This is due to the bandwidth limitation of the 1" video tape and the NTSC signal. We do not envision this to be amajor problem since the video is for a quick check only with the quality image to be recorded on film. We do, however, expect to'find a class of user for whom color video is adequate for their needs.

The recent advent of the digital time base corrector gives us one new dimension not possible a few years ago with a 1" video recorder. We can record our RGB picture as three separate images and using the time base corrector, dump the three images onto the video disk in perfect time registration for high quality viewing. Of course only ten seconds at a time can be viewed. As far as we have determined, this is the first time this will have been tried. This entire system (video disk, video tape, video switches, etc.) is under computer control. We feel that we will have a most advanced system for the production and editing of computer generated film.