Digital Post Production for Film

A Chapter for the Ninth Edition of The American Cinematographer Manual
by Bill Feightner, Executive Vice President, Technology, EFILM, LLC
Robert L. Eicholz, Vice President, Corporate Development, EFILM, LLC

Computer technology has been used since the late 1970's to enhance film images in post production. In 1982, Disney's breakthrough animated movie Tron (Bruce Logan, ASC) stunned the film industry by demonstrating just how far digital technology had evolved. Today, filmmakers and movie-goers alike take sophisticated special effects for granted.

Recently, with the advent of the Digital Intermediate process, digital technology's impact on filmmaking has taken another important step forward. This process, in which entire films are digitized, provides a whole new set of creative tools, allowing cinematographers unprecedented latitude in controlling and refining the final look of their film images.

A complete description of Digital Post Production for Film would fill many volumes. This chapter provides a high-level overview, and focuses on current and future industry trends.

REPRESENTATIVE DIGITAL SERVICES OVERVIEW

A large, worldwide industry has formed to serve filmmakers' digital post production needs. The digital services offered fall into three broad categories:

1) Acquiring and Digitizing Images

2) Enhancing and Manipulating Digital Images

3) Delivering Images

1) Acquiring and Digitizing Images

To manipulate images in the digital realm, those images must first be converted to industry-standard digital formats. Traditional film must be scanned, and video-originated material must go through image processing.

Film Scanning

Film scanning is the process of converting analog film images to the digital realm. Once images are in a digital format, post-production artists can manipulate them with computers (Figure 1). Conceptually, film scanners work much like desktop scanners. That is, a light is shined through each frame and the image captured and digitized onto an array, which translates the light into the computer bits and bytes needed to store and manipulate the image digitally.

The devices currently in use for digitizing film can be divided into two categories: Telecine and Film Scanner. Both devices allow the film negative to be digitized, though there are considerable differences. A telecine device runs at real time without mechanical pin registration and is generally designed to give on-the-fly interactivity while the film is loaded. Most of these designs

FIGURE 1 – Film Scanning (Digitizing) – Film Scanning (Digitizing)

Digital File Delivery Medium

Processed Film Film Scanner

(e.g. Cineon)
(e.g, FireWire Drive)

Negative (e.g.,ARRIScan)

are based on HD technology and are not able to scan the full resolution, dynamic range, and color pallet available on the negative film. A true film scanner on the other hand is a stable high quality digitizer with no interactive controls generally scanning at slower rates allowing the film to be mechanically pin registered.

The scanning parameters for a true film scanner are set before the film is loaded and are repeatable across multiple scanner units. They are designed to capture the full resolution, dynamic range, and color pallet available on the negative film for subsequent manipulation in the post production process. The combination of the spectral response of the illuminant, spectral notch filtering, and the response of the arrays, are tuned so that the scanner sees the negative the same way that print film does in standard laboratory printing.

Other important aspects of modern film scanners technology includes:

Scanning Speeds and Pin-Registration – Because of the need for steady images in Digital Intermediate and Visual Effects, pin-registered scanners are required for most applications. Pin-registration mechanisms are designed mechanically to close tolerances, so that each frame is scanned in exactly the same position as all other frames. This process reduces or eliminates the “weave” that sometimes results from non pin-registered scanners. The disadvantage of pin-registered scanners is that they typically scan at slower rates than non pin-registered scanners. When some degree of image weave is acceptable, non pin-registered scanners do offer a very fast and economical alternative.

Figure 2 provides a comparison of Scan times associated with various scanners.

In visual-effects, pin-registration of these elements is critical, because effects applications involve multi-layer compositing of foreground and background elements. Practice has shown that the critical tolerances of camera and optional-printer movements must be maintained in the operation of digital film scanners. This registration tolerance is +/.0001 inches (2.5 microns) which translates to ½ pixel in 4K sampled images. This ensures that element-to-element registration is transparent to the critical observer. With the emergence of high quality digital cinema projectors accurate

registration on non-effects shots will be equally important since there is no projector weave to hide non pin-
registered scans.

Resolution – The first generation of scanners generally scanned a 35mm frame at 2K (2048x1566 pixels) or 4K (4096x3112) (Figure 2). A common misconception is that a high-quality 2K resolution image is scanned at 2K. According to the Nyquist Frequency Rule, the theoretical maximum resolution a digital capture devise can resolve is only half of its sampling rate. Therefore, to achieve a true high-quality 2K can, the film image must actually be “double over-
sampled” at 4K, and then mathematically “down-sampled” to 2K.

Figure 2 – Scanning Rates and Resolutions Table

2K (double oversampled) 4K
Target Digital File Resolution 2048 x 1556
(82 pixels / mm)
4096 x 3112
(164 pixels / mm)
Scan Rate – Current
Generation Scanners
(Pin-registered)
Frame: 2-4 seconds/frame
1000’ Reel: 13.3 hours
Frame: 4-8 seconds/frame
1000’ Reel: 27 hours
Scan Rate – Next
Generation Scanners
(Pin-registered)
<1 Frame/Second
1000’ Reel: 4-5 hours
< 1 Frame/Sec
1000’ Reel: <4-5 hours
Scan Rate – Non-pinregistered
8 -24 Frames Per Second
< 20 minutes-1 hour

Dustbusting – Inevitably, even after extensive film cleaning and using scanners in sealed positive-pressure “clean rooms”, some dust particles are scanned and digitized. These image flaws are removed in a highly labor-intensive process called “dustbusting”. While several automated systems help find dust particles, a human being must still examine and fix every frame to ensure that dust particles do not end up on the final digitized image. More automated detection processes, based on Infra-Red detection, are on the horizon
(see next section).

Scanning: Next Generation -A radical new design from ARRI is available. 2004. It differs significantly from the traditional approaches. It will have specially tuned LED arrays as the illuminant which matches the response of the negative film. LEDs with associated control electronics do not have the flicker and stability problems associated with Xenon or incandescent light sources. It will employ a single CMOS two dimensional scanning array. While the negative is pin registered in place a snap shot of the entire negative is taken at one time instead of moving the film past a single line tri-linear array. The two dimensional CMOS technology is much faster allowing a single chip to make multi-level RGB samples for increased contrast sampling ranges and less noise. A forth infra-red channel is included for dirt detection. Sophisticated internal auto calibration will allow device independent scanning parameters to be loaded across multiple scanners with the same results.

2) Enhancing and Manipulating Digital Images

Once film images have been digitized, a wide variety of services is available to enhance and manipulate the images. Some of the most important include: manipulate the images. Some of the most important include:

Color Correction – Digital Color Correction, or Digital Color Timing is the process of manipulating color digitally to achieve the desired look for film projection, digital projection and video display. Traditional Color Timing is a photochemical process at the laboratory. Cinematographers view work prints of their films, and adjust color by "calling lights", meaning adjusting the way film is printed to achieve the desired look. In Digital Color Timing, this entire process is done with computer software.

Digital color correction allows the following benefits over traditional laboratory timing:

- Instant Feedback -In a typical digital color timing session, cinematographers see their films projected digitally, and instantly see the result of their decisions. By contrast, in traditional Color Timing, one or more days elapse between the color timing session and viewing of the results.
- Keying and Matting – In digital color timing keys and mattes provide the ability to apply different changes across each frame. For example, eyes of a subject can be made brighter, and then tracked through an entire scene, with the rest of each frame unaffected by this change. In traditional Color Timing, any changes made must be applied to the entire frame.
- Additional Options – Digital color timing provides many additional options not available in traditional Color Timing to enhance images, including image sharpening, defocusing (smoothing), contrast adjustments, color changes, and others.

Digital Assembly – Traditionally, filmmakers cut their original negatives to assemble their final film negative. Increasingly, filmmakers submit their original camera negatives to their digital laboratory. Appropriate selects are scanned digitally with handles. These selects are then assembled digitally into the final cut, using an electronic Edit Decision List (EDL).

Digital Titles and Opticals – Opticals, such as a fade out from one scene, and a fade in to a subsequent scene have been traditionally done manually, using complex mechanical devices. In the digital realm, all opticals can be completed quickly and seamlessly, with the ability to quickly view the result and make changes.

3) Delivering Images

Once digital images have been a finalized, they can be delivered in various digital and analog formats:

Film Recording – Film recording is the process of recording digital images on film (Figure 3). All images are recorded to fine grain intermediate film stocks, either from Kodak or Fuji.

FIGURE 3 – FILM RECORDIN3 – FILM RECORDING

Digital File

(e.g. Cineon)
Film Laboratory Processed Film

Film Recorder Unprocessed Film

Negative
(e.g.,ARRILaser) Negative

Laser technology is currently the only available technology that can completely fill the wide color gamut, high contrast range, and high resolving power of motion picture film. In the past before laser technology was readily available, other film recording technologies were used, but they fall short of today's demanding quality expectations.

Kodak manufactured the Lightning Film Recorder, the very first laser film recorder. This system uses three lasers (red, green, blue) to expose film negative in 10 bit log space. This recorder is still in use today.

With an installed base worldwide of over 200 recorders, ARRI Laser currently the sole manufacturer of laser film recorders. Even with the many advances in this field, film recording is still a relatively slow process. In fact, with only one recorder, it would take - days to film out an entire feature film. Figure 3 provides a summary of recording times.

Figure 4 – Laser Recording Table

2K 4K
Target Digital File Resolution 2048 x 1556 full aperture
(82 pixels / mm)
4096 x 3112 full aperture
(164 pixels / mm)
Individual Frame Recording
Time

Frame: 2.1 seconds Frame: 4.2 Seconds
1000’ Reel (11 minutes)
Recording Time
9.3 hours 18.6 hours
Film (7 full reels) Recording
Time
65 hours (one recorder) 130 hours (one recorder)

The most common resolution for film recording is 2K. However, in July 2004, Sony Pictures scanned and film recorded Spiderman 2 (Bill Pope, ASC) entirely in 4K at EFILM, LLC in Hollywood. As disk drive and computer processing costs continue to decline, industry observers expect 4K to become the new standard. Subsequently EFILM has created 4K Digital Masters for The Da Vinci Code, R.V., Casanova, Jarhead, Rent, Stealth and Ocean’s Twelve.

Another related trend is multiple negatives. Cinematographers using 4K images are encouraged to consider recording multiple negatives, as any benefits of using 4K resolution can be eliminated by the traditional Negative – Interpositive – Internegative – Print process and its associated multi-generational image quality loss (see Future Trends below).

Other Delivery Media – In additon to film, digital images are delivered on a wide variety of other formats, including:

- Tape (e.g., D5, D1)
- Disk Drives (e.g., FireWire technology)
- Digital Cinema Masters for digital projection (e.g., QuVIS)
- Video Masters (for subsequent conversion to NTSC, DVD, PAL, DVD, and other common formats)

INDUSTRY SERVICES, PRODUCTS, AND MARKET SEGMENTS

The Digital Post Production services described above are combined into service lines for various purposes. The most common are Special Effects, Tape to Film, and Digital Intermediate.

Special Effects – Special effects are now included in virtually every motion picture. The special effects process begins with digitization of original images. Film-originated images are scanned, generally on a 2K pin-registered scanner (Figure 5). The images are subsequently manipulated by computer software programs and then output to film. Because of the precise nature of digital manipulation, use of a pin-registered scanner to produce steady images without weave is mandatory. Video or 24P-originated images are imaged processed and / or transferred to the appropriate digital format.

FIGURE 5 – Special Effects

Tape Input

(e.g. HD Cam, 24P)

Even average feature films typically contain 75 – 150 special effects shots. Effects-laden films can contain 500 –1000 or more shots. A recent trend is toward special effects shots that do not look like special effects. Common examples include:

- Wire and negative scratch removal
- Addition of rain, snow, and other weather elements
- Changing seasons with color changes
- Changing day scenes to evening scenes

Tape to Film – As a result of the increasing quality and decreasing costs, many independent and even some mainstream filmmakers now originate on video and digital 24p cameras, rather than film. Recent examples include Once Upon a Time in Mexico (Robert Rodriguez, Cinematographer) and Star Wars: Episode II -Attack of the Clones (David Tattersall, ASC). Like Special Effects, the Tape to Film process involves acquiring images, manipulating and enhancing them, and recording to film (Figure 6). There is a growing trend at film festivals to forego the film print and instead project digitally, thus eliminating film entirely. This trend is expected to continue and expand.

6). There is a growing trend at film festivals to forego the film print and instead project digitally, thus eliminating film entirely. This trend is
expected to continue and expand.

Digital File
Processed Film
Original Camera
Negative
Film Scanner or
Image Processing
Digital Image Manipulation
-Compositing / Roto
-CGI
-Color Correction
Film
Recorder
Lab
Processing /
Negative

Recently Dean Semler, ASC used the Genesis Camera and the EFILM Colorstream™ package for on set preview on Click and Apocalypto allowing an accurate, immediate emulation of film output.

FIGURE 6 – TAPE TO FILM

Tape Origination Image Processing

Digital File

Film

Lab (eg HD Cam, 24P) Digital Image Manipulation Recorder

Processing /

-Compositing / Roto

Negative

-CGI

-Color Correction

or

Image
Translation

Digital Cinema
Master
(e.g., QuVIS /
QuBIT)

Digital Intermediate – Digital Intermediate uses a comprehensive suite of services to create Digital Master of entire films (Figure 7). In this process, entire films are scanned (or imported in the case of 24p digital capture), assembled, color corrected, and then recorded back to film from the final Digital Master. In addition, the Digital Master is used in a computer-based translation process to create a video master, which is used to create video and digital cinema masters.

FIGURE 7 – DIGITAL INTERMEDIAT7 – DIGITAL INTERMEDIATE

High
Resolution
Scan
Digital Mastering Process
Create Digital Opticals
Conform Scans, Vfx,
Opticals to EDL
Dust Bust
Digital Color Time
Title
“The Digital Master”
Viewing
Digital Projection
(Calibrated)
Camera Telecine
Off Line Edit: EDL
Visual Effects 2D / 3D
Digital Cinema
Laser Record IP
Video Masters

TECHNICAL ASPECTS

Image Capture and Standards

Modern motion-picture original negative stocks capture images with red, green and blue records representing more than an eleven stop scene exposure range. The negative captures more latitude than can be reproduced on the print. The characteristic curve for the digitized film negative as well as a projected print film is illustrated in Fig. 8. By adjusting the respective red, green, and
blue printer lights, the lab timer can set the exposure range of the negative that the print will see.

It is important to maintain this extended latitude during the Digital Intermediate process. The scanner should be zeroed on the D-min of the specific film stock that is being scanned. The typical industry scanning metric of choice is logarithmic with 10 bits allocated to a 2.0 plus density range. With a typical exposure, a 90% white card will produce a digital code value of
approximately 685, with 2% black falling at approximately 180 code values. The range of code values above 685 provides headroom for specular highlights and light sources, or extra latitude for overexposure in shots that pan or move from shadows to bright sunlight.

FIGURE 8 –RELATIVE LOG EXPOSURE

Rel Log Exp02505007501000-2.50-2.00-1.50-1.00-0.500.000.501.001.5010-b Dig Code ValuePrinting DensityProjected Film Print
The color fidelity of the original film images is maintained by digitizing the film in terms of printing density. In order that the scanner “see” the film the same way in which it was

printed in dailies, the spectral response of the digital film scanner is designed to match that of the motion-picture print film in standard printer (Fig.9). This ensures that the digital record contains the same color characteristics as the original negative film. It should be noted that printing density is similar to (but not exactly the same as) the status M density filters used to measure negative films.

The 10-bit log Cineon digital film format has become the de facto standard for the scanning and exchange of images between digital film facilities. Digital film scanners and recorders manufactured by several companies have been designed to this standard. Most of these scanners -bit log Cineon digital film format has become the de facto standard for the scanning and exchange of images between digital film facilities. Digital film scanners and recorders manufactured by several companies have been designed to this standard. Most of these scanners

FIGURE 9 –SPECTRAL RESPONSE OF TYPICAL DIGITAL FILM SCANNER AND STATUS M

Wavelength (nm)
00.511.522.533.5350400450500550600650700750Spectral ResponceStatus MScanner

support selectable sampling resolutions of 4096 (4K) or 2048 (2K) across the width of a 35mm full-aperture image. To understand the impact of sampling resolution on image sharpness, one can look at the system Modulation Transfer Function (MTF) for a series of sampling resolutions as shown in Fig. 10. This shows significant MTF gains when going from 1K to 2K, but diminishing returns as the sampling resolution is increased from 2K to 3K, with very little gain above 3K. In current practice, most shots are scanned and processed at 2K except when digital zoom or repositioning is required when a shot might be scanned at 4K and resized to 2K for processing and final output. Although processing images at 4K is expensive, and while most additional detail in 4K digital images is lost in film printing and projection, resolutions higher than 2K for scanning and archiving will ultimately gain momentum. It is important to note the growing trend of producing multiple digital printing negative which can allow these increased 2K plus resolutions to actually be seen on the cinema screen.

FIGURE 10 –MTF RESPONSE VS> SAMPLING RESOLUTIO–MTF RESPONSE VS> SAMPLING RESOLUTION

Frequency (c/mm)
0.000.200.400.600.801.001.200204060Relative Responce1K2K3K4K5K

Displaying Digital Film Images

The intent of displaying the digital images is usually to emulate how the audience will see the final delivered product. Extreme care must be taken to assure accuracy. Large screen projectors have difficulty emulating electronic display devices. This is because of film's inherent wide color gamut, high contrast range, high resolving power, and complex nonlinear inter-color effects due to the complex chemical processes which produces the color images. CRT displays most often used to date, lack the color pallet available on film and allow only a subset of the total film colors to be displayed. To make this subset of colors come close to matching film, complex three dimensional color mappings are needed to impart the non-linear transfer function of projected film. CRTs are not inherently stabile devices so they must be calibrated often. Monitors such as those from Barco and Sony have internal stabilization electronics and built in calibration systems to assure stability. The viewing environment is also critical and should match the darkened cinema.

Digital projection technology has matured to a point that it can come close to emulating projected film. To date the DLP TM from Texas Instruments can attain a contrast ratios of over 2000:1 with a color pallet approaching film. With the extremely stabile digital light valve technology, along with the built in color management systems, predictable stabile images are assured. Also, complex three dimensional color mappings are needed to impart the non-linear transfer function
of projected film. The size of the digitally projected image can also match its film counterpart.

Most important when digitally previewing film images is that the entire system be end to end calibrated, including the film processing laboratory, to assure accuracy. If the images are destined for delivery to other display venues, then the ability to emulate these devices is important. If the destination is to multiple display venues, then the ability to translate the look of the delivered images into each device's look space is required.

Quality Control and Calibration

Digital filmmaking requires quality control of the end-to-end process to ensure that the digitized images can be seamlessly intercut with live action. Maintaining the technical specifications of contrast range, color fidelity, resolution and registration are part of the process. With many of today's feature-film productions farmed out to multiple postproduction facilities for visual effects, the consistency from shot to shot and from facility to facility is also very important.

While it is possible with a calibrated monitor to get an approximation of how the final film print will look on the projected print, different display technologies are needed. In order to achieve accurate simulation, full closed loop system calibration including the processing laboratory is required. This includes daily scanner, display, recorder, and sensitometric control of the
processing laboratory. In order for the display device to match a print at a given laboratory, multidimensional spectrographical characterizations of the resultant negative and print are required in order to develop multi-dimensional lookup tables for the display devices.

INDUSTRY TRENDS

Technical and business process advancements continue to accelerate in Digital Film Post Production. Some of the more interesting current trends include:

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- Multiple Digital Negatives: Increasingly, studios are creating multiple negatives for their features. Using Kodak's Estar negative, this allows laboratories to strike prints off of multiple original digital negatives. By contrast, the traditional Negative, IP, IN, Print process results in three generations of image degredation. By filming out multiple negatives, all theater prints become "show prints." The image improvement is significant, even to less experienced movie goers. This trend is rapidly accelerating, resulting in a corresponding need for capacity increases at digital post production facilities.
- Auto-Assembly: Early digital intermediates were scanned from cut negative Increasingly, production companies now submit EDL's, which are used to electronically assemble scanned selects. A side benefit of this process is that because the negative is not handled in an editing room, the film is less vulnerable to dirt, dust, and scratches.
- Digital Cinema Previews: With the advent of auto-assembly, and quality 2K digital projection and DCI standardization, some studios are electing to do a series of digital cinema previews prior to locking their films. Using revised EDL's, features can be reedited, re-color corrected, re-assembled and then previewed digitally at multiple locations.
- Reduced Special Effects Costs: Recent significant reductions in special effects tool costs have reduced overall costs for visual effects..
- Digital Archiving: As the number of digital masters increases, so does the need to consider the archiving implications. Unlike film, digital masters on tape are vulnerable to changing technologies rendering formats obsolete and possible corruption of digital files. Studios are researching the best approaches to ensure that their digital assets can be preserved just as long as their archived film. Because this is a technically complex issue, many industry groups and corporations are working standards and solutions. Within the next few years, a new generation of companies and services will evolve to serve the digital archiving needs of studios. In the next few years, a new generation of companies and services will evolve to serve the digital archiving needs of studios.

Bill Feightner, Executive Vice President, Technology is an Associate Member of the ASC. Mr. Feightner was one of the founding owners of EFILM, and is in charge of envisioning, researching, developing, and implementing all aspects of EFILM's Digital Laboratory Services.

Robert L. Eicholz, Vice President of Corporate Development at EFILM, oversees management and operation of EFILM's technical groups, including software development, engineering, and imaging.

This chapter contains several excerpts from a similar chapter written by Glenn Kennell (Director of Technology Development, Texas Instruments DLP Cinema) and Sarah Priestnall (formerly of Kodak's Cinesite) for the previous edition of the ASC Handbook.