Digital Intermediates

A DISCREET PERSPECTIVE ON HOW THE DIGITAL INTERMEDIATE PROCESS IS OFFERING FILMMAKERS POWERFUL NEW CREATIVE OPPORTUNITIES, ESPECIALLY IN THE AREA OF COLOR GRADING

ABSTRACT

This paper focuses on the digital post-production of film, and in particular digital intermediates, with particular emphasis on the color grading / color correction process. It will attempt to explain how recent developments in digital technology have impacted this highly creative part of the filmmaking process, offering artists and filmmakers new options when creating their visual art.

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INTRODUCTION

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From acquisition to distribution, an increasing number of film production and post-production processes are being accomplished digitally. One such process, and a relatively recent one to go digital, is the digital intermediate.

Defining digital intermediate

The term digital intermediate is relatively new and is used in slightly different ways by different film professionals. In a recent online article, Film and Video Magazine quoted Randy Starr, then Cinesite VP of business development, as defining a digital intermediate to be *"a project that has been digitally color corrected and output to film.[1]"* This definition refers in fact to two processes, the digital alteration of the color values in an image (color correction) and the printing of the result back to a film negative. It is also close to the definition used throughout this document (see Digital Film Glossary).

It should be noted that none of the processes Starr refers to are in fact new. They have been used for more than a decade to create visual effects for film. What is new is the application of these processes to an entire project as opposed to only selected scenes or 'shots,' enabling the role of digital film to expand beyond the domain of visual effects into the world of cinematography. Recent advances in digital technology have made this both technically feasible and cost effective.

Digital intermediates and digital masters

Another term that is used somewhat interchangeably with digital intermediate is digital master. This is because both terms refer to the same media asset – typically digital film images residing on a mass storage device. However, the two terms differ in that they are used to describe two slightly different purposes for the media asset. The term *digital master* is used to refer to a media asset's purpose as a reference source (or master) from which further copies (or versions) can be derived (including versions at different resolutions and in different formats such as film, HDTV, and analog/digital video for TV, VHS or DVD).

digital intermediate is used to refer to a media asset's transitional (intermediate) nature – a state between the asset's original (acquisition) and final (distribution) forms. Secondarily it is assumed that there is a definite purpose for this 'intermediacy' such as color grading, digital mastering or visual effects creation and integration. It is therefore easy to see how a digital intermediate can act as a digital master for versioning purposes, and that digital masters can indeed refer to the very same media assets as digital intermediates.

Digital Film Glossary

CGI – Computer Generated Imagery. Digital images created on a computer but destined to be projected in a theatre, either integrated with live footage (as visual effects) or as a purely computer generated animated feature such as *Toy Story 1* and *2*, *Monsters Inc*. or *Shrek.*

Digital Film – Generic term for high-resolution film images that are in a digital format. Historically digital film referred to CGI or to selected film shots that had been scanned (digitized) for visual effects work. Today it is used more generally to mean 'the digital equivalent of celluloid film'.

Digital Intermediate – Specific term for the digitization of entire film reels or movies as an intermediate (post)-production process, primarily for the purpose of digital color grading, digital mastering or effects work, and generally with the intention of printing the result back to film.

Digital Cinema - The use of digital alternatives (to celluloid, optical or photo-chemical technologies) in the distribution and display of film and by extension, the production, shooting (acquisition) and post-production of a moving picture intended for digital cinema display.

[1] Digital Clarity by Carolyn Giardina, Film and Video Magazine 2003

Digital intermediates for color grading

Without a digital intermediate of some sort, digitally color grading a film would of course be impossible. But why are the two so often inextricably linked? The answer lies in the reason why filmmakers create digital intermediates. Few do it just because they can. The main reason most filmmakers consider digitizing an entire film, which is a relatively expensive process, is to have more creative control over how the film will look when finally projected. There are other reasons of course, but this is by far the most frequent – especially when it comes to justifying the digitizing of films that are not designed to be visual effects extravaganzas. For cinematographers and filmmakers, software-based non-linear color grading is one of the more exciting new creative capabilities to have emerged from the recent advances in digital technology.

Digital Grading and Cinematography

Leading cinematographers are excited by the creative prospect of digital grading as Newton Thomas Sigel, ASC recently told the American Cinematographer: "The digital intermediate is a tremendous opportunity to have more control [over the image]. You're continuing the process of cinematography when you color correct your film and you can have a direct impact almost as great as when you did your original photography.[2]"

Digital color grading – the visual impact

Digital color grading systems allow directors of photography to work together with a colorist (or digital color timer) in ways that were previously inconceivable. They can visualize the film more holistically, either on a computer screen or projected, and work interactively with the colorist to adjust both light and color in subtle and complex ways and to incredible levels of detail. This can significantly augment the visual impact of a film, as has been demonstrated in such ground-breaking films as *Pleasantville*, *O Brother*, *Where Art Thou* and more recently *The Lord of the Rings*: *The Fellowship of the Ring* and *The Lord of Rings: The Two Towers*.

The transition from film lab to digital suite

Film color timing has expanded far beyond photochemical and optical processes – restricted by the physical properties of the film medium – to encompass new digital workflows where images are capable of being manipulated to an almost infinite degree. The optical and chemical processes continue to remain indispensable for calibration and quality control purposes when developing negatives (including those printed from digital intermediates) and generating distribution prints. However, the creative color and lighting decisions are rapidly migrating from the film lab to digital color grading suites.

The final editing and conforming of film is also undergoing a digital transition. This process has remained relatively unchanged for nearly a century and is a strictly manual process of splicing pieces of film stock together. However, the new digital intermediate process is completely non-linear in nature and modern systems are no longer confined to "offline resolutions" but can edit 2K and 4K scans, providing a compelling alternative for digital finishing (the creation of a digital master negative).

Together these trends provide filmmakers with a huge creative advantage in that editorial, color and lighting decisions can be made and revised at anytime during production – right until the moment of final print. Furthermore, the process of making a film can now be highly 'parallelized' with multiple stations working on different aspects of the same scene simultaneously.

With traditional methods, the creation of a feature film involves several intermediate stages[3] of film processing and optical grading before the final master is ready for mass printing. Digital intermediates eliminate the need for much of this 'intermediate' lab processing. Digital methods also help bypass interpositive/internegative stages, producing a fully graded and conformed negative for printing distribution copies. Moreover, a digital master can produce an unlimited number of high quality 'original' negatives for large printing runs significantly improving the overall quality of the distribution: in one sense each print becomes a showprint.

[2] A Flexible Finish by Debra Kaufman, American Cinematographer, April 2003.
[3] Printing Rushes or work prints, answer prints, interpositives and internegatives, printing optical effects and color timing and more.

As a result, the use of digital intermediates is increasing and is expected to double to over 50 productions in the US this year (2003). Even the labs themselves have not been standing idle. From Éclair Laboratoires in France, to Deluxe and Technicolor in the US, film labs worldwide are expanding and augmenting their traditional photochemical processes with new digital intermediate ones.

Digital trailers

One indication of the rapidity at which digital methods can take root is to be found in the digital production of movie trailers. Not more than three years ago, trailers were mainly produced optically with fewer than 20% done digitally. Last year that number had increased to 80%. Several major studios now insist that all their trailers be produced digitally. What drove this transition? The faster project turnaround times and the greater creative potential of digital systems. Over the last few years, the performance and creative toolsets of high-end digital film systems have enabled studios to produce trailers with more visual effects in less than half the time it took to do optically – and without compromising image quality.

Digital film in commercial post-production

There are an increasing number of post-production facilities worldwide that are capable of scanning film at 2K and higher resolutions. This trend towards high-resolution film scanning can be expected to continue as high-end facilities adapt to better cater to their top clients. Digital film workflows help seduce quality conscious, upper tier clients – those that have the highest production budgets. Most major productions, whether they are commercials, music videos or TV programs, are shot at the highest possible quality – which today generally means shooting on film and ultimately helps guarantee the value of the final master asset. In the past, technology limitations and high costs prevented the full quality of film from being retained throughout the broadcast/ commercial post-production process. Instead the film was converted to video using a telecine. Today's digital technology removes many of those constraints.

The ability to obtain a superior product is compelling to most producers. Their production assets are better protected by digital masters from which any format, including a print for theatrical display, can be derived without any loss of quality. For example, the instant visual impact of seeing, a projection of car commercial derived from a 2K film print is incomparable to watching a projection of up-converted standard definition video in almost any movie theatre.

Today many high-end post-production companies are gearing up for 2K data (or greater) workflows confident that this will give them a competitive edge. Indeed, many of the companies that have adopted 2K data workflows report better revenues, less price erosion and even growth. Those showing the highest revenue growth tend to be those who have successfully differentiated themselves through skillful marketing of their high-resolution digital film capabilities.

High Resolution Commercials

"In the commercial world it's primarily cinema that's caught people's attention… Actually going over to the theatre and seeing your product on the cinema screen is a completely different experience [to watching video] – much more powerful."
Nansi Thomas – Toybox, Toronto Canada

Digital film restoration

The advent of HDTV and digital intermediate technology, combined with the need for content fuelled by consumer demand for DVDs and digital television programming has increased demand for content and consequently interest in resurrecting and restoring old movies. This market has increased rapidly over the last few years and is likely to continue its rapid expansion as restoration technology gets better and digital intermediate workflows become more affordable.

DIGITAL FILM – AN INDUSTRY IN TRANSITION

New production requirements

The requirements placed on film producers and directors in order to successfully bring their projects to market are becoming increasingly complex. Only a few years ago, the principal concern of a film producer was to create a film that would sell well in movie theatres – and perhaps provide good merchandising opportunities. The requirements of other distribution methods, such as TV programming and VHS, rarely needed to be considered during movie production since they were almost always generated from fairly straightforward telecine scans of the original film material. New content was rarely added after a movie had been released; although TV versions were sometimes edited to remove content that was considered unsuitable for the viewing audience by the broadcaster. The rise in popularity of DVDs however has significantly changed the requirements of modern film production.

Early DVD production was not that different from VHS video production, but producers and filmmakers quickly realized that this new medium provided significant new creative and revenue opportunities. The DVD version of a movie can now be extremely rich in bonus content and significantly different from the original feature. DVD material can, and often does, feature re-graded, re-edited footage such as director's cuts and extended versions, deleted scenes, unmasked footage[4], making-of documentaries, interviews, games and more. Producers realized that if they planned the DVD content well, they would not only sell more DVDs but also have an opportunity to sell several different DVD versions of the same film to the same customer.

To avoid excessive production costs, and to ensure the creation of compelling content, producers now have to rigorously integrate DVD requirements into their production plans. Doing so often increases the attraction of using a digital intermediate for production since it provides a highly flexible master from which new versions and edits can be created almost instantly.

An additional complication is the multitude of different broadcast formats that have developed in recent years. A feature film today is likely to require not only PAL and NTSC formatting for broadcasting, but also HDTV. As a result it is more important than ever that a given production be able to deliver a wide and rich range of content and formats – only then can the producer maximize the possible revenues he/she can obtain through multiple distribution opportunities.

Successful DVD Production

The success of the DVD version of Peter Jackson and New Line Cinema's *The Lord of the Rings: The Fellowship of the Ring* is a case in point. The DVD content was meticulously planned in advance and tracked throughout the production of the film. This included everything from documenting the production for "The making of…" features to shooting extra footage for an extended version with full post-production and visual effects work.

The end result was not only the best selling DVD of all time for New Line Cinema, selling 11.3 million units and generating the highest revenues of any DVD title in 2002,[5] but also a highly successful Special Extended Edition. According to New Line Cinema, within three months of its release, three million units of the Special Extended Edition had been shipped worldwide making it the most successful Special Edition to that date.

4   35mm film stocks expose a 4:3 area that is then masked to provide the widescreen projection. TV versions are usually made by cropping this already reduced widescreen image to produce a new 4:3 (pan & scan). Today, some directors prefer to unmask the original crop to get the original 4:3 exposure transferred to video – this allows them to show more of the image on the TV version and produce a 4:3 (which is more popular with TV audiences) without losing any of the original scene.
5   Data source: New Line Home Entertainment Press Release, Jan 23, 2003.

New television formats

The advent of formats like high definition video and DVD has significantly impacted media production technology and workflows. Moreover, a huge shift in the industry has occurred with the introduction of DVD. Previously, TV and video versions could be taken care of at a later time.

With the need to produce and distribute in multiple formats, there arose a variety of frame rate and aspects ratio related issues. These are easier to address in the higher quality HD or 2K realms, and mastering in these formats is becoming an attractive option for motion picture, television and commercials producers. Capacity to support 2K is growing and full service bureaus such as Toybox in Toronto, offer a 2K data finish in approximately the same time and price range as an HD finish.
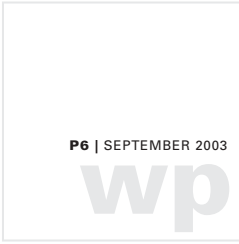
Digital Intermediates and Television

HBO has emerged as a major force in the creation of high-quality programming, and has used digital color timing/mastering for such high-profile projects as *Band of Brothers*, *Path to War*, and *Conspiracy*. As the excerpt from a recent Editor's Guild Magazine article explains, HBO has found compelling reasons for adopting 2K digital intermediates as the finishing format of choice:

"In some cases, digital intermediate can even make sense without a film release. Cynthia Kanner, HBO Films vice president of post-production, points out that there is currently no way to tell what the life span of videotape will be. Film is still the most reliable form of long-term storage, so even if a show were assembled digitally, HBO would still cut negative for archival purposes. HBO Films started using digital intermediate three years ago… Vice President of Production Jay Roewe expects 30 to 40 percent of their future shows to employ digital intermediate in some form, primarily for creative reasons.[6]"

Film post-production workflow

After film is shot and taken out of the camera it does a lot of traveling, undergoing many transformations before it is finally projected in the cinema (see diagram on page 7).

Pure film post-production workflows require a complex series of intermediate steps in order to produce the final product, and while the actual steps will vary depending on the requirements of each production, the overall process has several limitations:
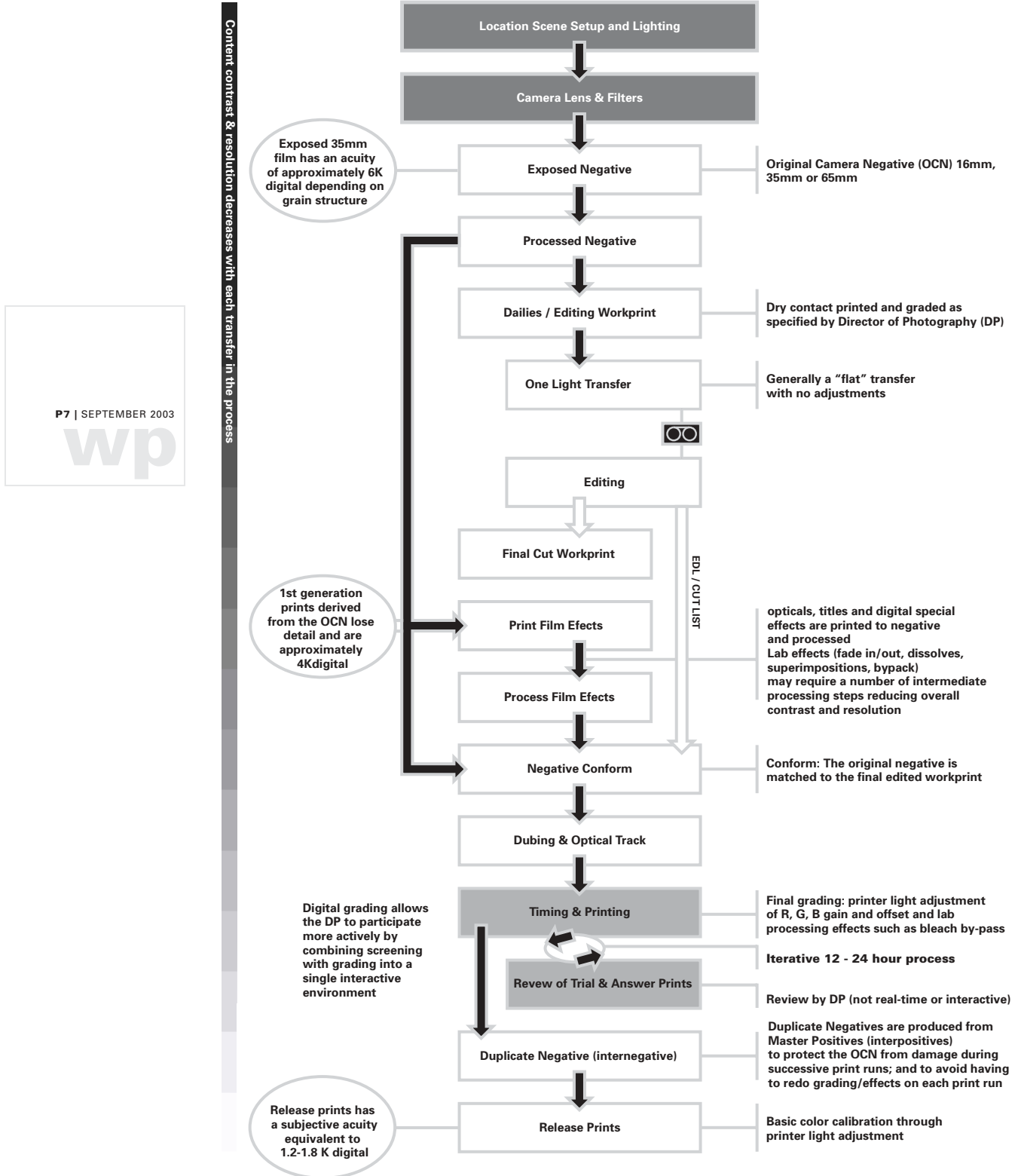
- Film is sensitive and prone to damage. Each processing step increases the number of minor defects (dust and scratches) as well as the risk of major damage or destruction.

- The process of transferring an image from one piece of film to another through optical or contact printing causes degradation in the quality of the image. Image information such as fine detail and subtle color or contrast differences is often lost.

- Film processes are essentially linear and non-interactive. Changes to the film need to be chemically processed before they can be viewed (generally 24 hours later).

- The artist's creativity is constrained by the physical limitations of the film medium, which limits the type and scope of the modifications that can actually be made.

As a result, digital technologies have been replacing many of the film processing techniques used in post-production. This has been facilitated by the rapid improvement of computer and digital imaging technologies combined with their ever-decreasing costs. Critical areas of film post-production workflows, such as editing, visual effects and opening titles have already irreversibly moved into the digital realm and others like color grading are set to rapidly follow.

[6] Digital Intermediate for Film by Rainer Standke, Editor's Guild Magazine, Vol 3 No. 23.

A typical example of film workflow (simplified)

Content contrast & resolution decreases with each transfer in the process

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Location Scene Setup and Lighting

Camera Lens & Filters

Exposed Negative

Exposed 35mm film has an acuity of approximately 6K digital depending on grain structure

Original Camera Negative (OCN) 16mm, 35mm or 65mm

Processed Negative

Dailies / Editing Workprint

Dry contact printed and graded as specified by Director of Photography (DP)

One Light Transfer

Generally a "flat" transfer with no adjustments

Editing

Final Cut Workprint

EDL / CUT LIST

1st generation prints derived from the OCN lose detail and are approximately 4Kdigital

Print Film Efects

opticals, titles and digital special effects are printed to negative and processed

Lab effects (fade in/out, dissolves, superimpositions, bypack) may require a number of intermediate processing steps reducing overall contrast and resolution

Process Film Efects

Negative Conform

Conform: The original negative is matched to the final edited workprint

Dubing & Optical Track

Digital grading allows the DP to participate more actively by combining screening with grading into a single interactive environment

Timing & Printing

Final grading: printer light adjustment of R, G, B gain and offset and lab processing effects such as bleach by-pass

Iterative 12 - 24 hour process

Revew of Trial & Answer Prints

Review by DP (not real-time or interactive)

Duplicate Negative (internegative)

Duplicate Negatives are produced from Master Positives (interpositives) to protect the OCN from damage during successive print runs; and to avoid having to redo grading/effects on each print run

Release prints has a subjective acuity equivalent to 1.2-1.8 K digital

Release Prints

Basic color calibration through printer light adjustment

6k

NOTE: The digital resolutions (6K, 4K, 1.2K) are generalizations. Actual results vary considerably and the ability of film to resolve detail is dependent on several factors including light intensity, exposure time and contrast ratio

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Engineering Film For Digital Purposes

Filmstocks like Kodak's specialty SFX 200T color negative are an interesting example of how film can be engineered to meet the needs of digital film post-production – and in particular visual effects photography.

The SFX 200T's ultra-fine grain provides enhanced resolving power and reduces red emulsion layer edge effects through specific development inhibitor releasing couplers that reduce the spread of the cyan dye cloud during the development process. This produces a sharper image in the red layer than in the green or blue layers.

As a result SFX 200T enables foreground action to be isolated more effectively from a green or blue screen background when scanned into a computer. This facilitates the task of the compositor when keying fine detail in digital compositing and visual effects systems.

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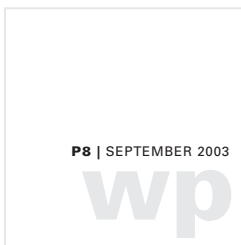
Film has a unique property in that it is capable of constant evolution and yet is highly consistent through time. Modern film emulsions bear little resemblance to those of the early 1900s yet a modern stock can still be run through an old hand-cranked camera (albeit with a little tweaking).

For more than a century the rapid pace of technological innovation in film has driven continual improvements in both the quality and capabilities of film itself[7] – from the highly precise motion control rigs of today to the ultra-sensitive, fine-grained silver emulsions used to create the latest filmstocks.

However, by the late 1980s, digital technology had reached a point where an image could be effectively disassociated from the physical film medium and processed digitally. This radically changed the way that film post-production was to evolve. For the first time, film images could be creatively altered in ways that were previously impossible. As a result, digital visual effects saw a rapid rise in popularity.

As digital technology improved and computers became faster and cheaper, the volume of digital film effects increased dramatically. By the end of the 1990s filmmakers were manipulating entire feature films digitally and it was obvious that digital film was an irreversible part of creative filmmaking.

Film manufacturers, cognizant of the inevitability of digital post-production, have optimized their products to better serve the needs of filmmakers intending to work with digital images. Much of the research behind new stocks such as Kodak's SFX 200T, Vision2 500T and FujiFilm's Reala 500D has been driven not only by the need to capture higher quality images but also by the requirements of translating film into the digital world.

Kodak was one of the first companies to recognize the potential of digital technology as a means of empowering filmmakers with greater creative freedom. After developing a high-resolution digital film scanner and recorder, Kodak went on to lay the groundwork for the DPX[8] file standard helping standardize many of the parameters still used in digital film scanning today.

Over the last few years, the rapid increase in both storage capacity and computer performance combined with decreasing costs have made the processing of large amounts of digital data both feasible and cost effective. As a result, the number of frames that could be processed digitally on a given budget and schedule increased dramatically.

New scanning technologies have also significantly increased the rate at which film images can be translated into their digital equivalents thereby enabling filmmakers to move from just scanning selected shots as required for complex visual effects work to scanning entire movies ushering in the era of the digital intermediate.

By 1998 films such as Gary Ross's *Pleasantville*[9] (New Line Cinema) were able to introduce new levels of visual creativity. The floodgates had opened as the film industry started to realize the new creative possibilities that digital intermediates offered.

[7] For the sake of simplification developments in audio technologies and non-linear offline editing are ignored in this paper. This paper focuses primarily on the use of digital images that are destined to be part of the final film product.
[8] DPX is defined in the SMPTE 268M standard and is derived from Kodak's Cineon raster file format with slight modifications to the file's header.
[9] *Pleasantville*, involved 113 minutes or 163,000 frames of scanned film graded by Cinesite on Kodak Cineon software systems (cinematographer John Lindley).

Economic factors

Managing a successful production/post-production business has become an increasingly challenging task, one that has been compounded by recent worldwide economic recessions. As a result, producers are actively exploring more efficient and cost-effective production technologies and techniques, which in turn has contributed to increased interest (and therefore demand) in digital technologies. Proponents of digital technologies regularly quote the ability of digital technology to both help reduce production costs and give artists new creative tools.

More and more film productions are embracing digital formats. This has been facilitated by the introduction of cheaper and faster scanning technology, which in turn has significantly reduced the cost of creating digital intermediates[10]. As a result, some digital services now cost significantly less than even a year ago.

As an example, scanning costs in some major production centers, although highly variable, depending on the amount of scanning required and ancillary services purchased, have dropped from an average of USD $1.50/frame in 2001 to less than USD $0.75/frame today. However, new revenue opportunity now exists in color correcting and grading the digital scans.

Many leading production facilities, film laboratories and post-production houses see digital film as an area of opportunity for future growth, whether as a means of diversifying into feature film work or as a means of enabling their clients who 'shoot film' to 'post film.'

Posting a TV commercial or program at 2K offers the client the highest possible quality master from which to derive final versions. It ensures that production quality is maintained at the highest level throughout the process, so that the quality compromises that have to be made when transferring to video can be made at the end of the production cycle, not at the start. As a result, more and more high-end post facilities are purchasing 2K capable telecines.

Adoption rates

The number of film productions going through a digital intermediate process has increased at an astonishing rate. In 2000, less than 2% of US productions were digitally graded, today more than a quarter of all major US productions are graded using digital systems[11].

Traditional film-based grading and conforming workflows still work well, are predictable, and produce high quality results, so many films continue to be produced as before. As a result, the percentage of digital intermediates being produced worldwide is significantly lower than in the United States, with the exception of countries like France, where the use of digital intermediates is rapidly increasing. Of the 200 or so French films produced in 2002, nearly 30% were graded as digital intermediates[12].

Most of these films are scanned at 2K and graded using highly specialized software solutions that have been designed to meet the specific requirements of film. These software solutions provide the advantage of not being constrained by hardware processing limitations and therefore being easily customizable, much like the technology used at leading digital intermediate labs such as EFILM Digital Laboratories in Hollywood, California.

Diversifying Into 2K Post-Production

"We have picked up additional revenue streams over the last year, and we are actively looking at centralized server-based solutions for intermediate storage of our work. We are also seeing more requests for data. Additionally, this past year 50 percent of our shows went HD - increasing our need for telecines and tape decks. From a business perspective, it makes sense to seriously evaluate a shared storage and digital color correction system."
Rory Lubold, The Post Group, Hollywood, California

"The rates are still firm in color correcting today... [and] we've opened up new revenue streams with 2K - trailer and foreign language versions … we're now scanning full features."
Simon Precious, The Moving Picture Company, London, UK

[10] As more productions embrace digital workflows and volumes increase economies of scale can be introduced which further reduces the per-frame cost of a project
[11] Data obtained from Discreet customer surveys and market research
[12] Data obtained from Discreet customer surveys and market research

The desire for creative control

Creative processes that move from a traditional workflow to a digital one usually do so in phases. For the digital intermediate process to be widely embraced it must offer a wide range of advantages in terms of creativity, quality and economics.

With the advent of digital grading technology, filmmakers now have an unprecedented level of control and a wealth of new tools at their disposal. Movies such as *O Brother, Where Art Thou?*, *Le Fabuleux Destin d'Amélie Poulain* and *The Lord of the Rings* trilogy have ushered in an age where defining the final 'look' of the film can be as carefully controlled (to the pixel) as the editing or special effects.

By offering the ability to apply multiple layers of primary and secondary correction to an image without any loss in quality, digital intermediates enable the director of photography and colorist to work with an image like a painter, subtly and profoundly adjusting the elements of light and color until their creative vision is met.

This artistic empowerment is furthered by the availability of tools that have previously been constrained to the realm of visual effects. There are tools such as automated tracking that can be used to apply extremely specific color changes to moving objects; and plug-in filters that can simulate anything from Tiffen lens filters and silver retention techniques, to visual treatments that cannot be created in the physical world.

Digital intermediates enable the director of photography and colorist to work with an image like a painter, subtly adjusting the elements of light and color until their creative vision is met

Now that the technology has reached a point where digital intermediates are no longer cost-prohibitive and computers can process and display high resolution imagery with greater speed and ease, the demand for these new creative tools is harder to deny and digital intermediate adoption is increasing rapidly.

Color correction of standard definition television signals in YUV color space has been around for some time but film color correction has remained elusive until recently – the massive amounts of data storage and processing power needed work with film kept grading an entire movie an elusive 'Holy Grail' for digital non-linear technologies.

Many of the tools for digital film color correction have been available in film visual effects systems like Cineon and non-linear for more than a decade. While the process could deliver excellent quality, the speed of the technology was too slow to be widely used for large-volume digital film processing, and the technology did not dramatically impact the overall creation of films. However, over the last 24 months advances in computer technology have allowed them to expand more effectively (and economically) into the digital intermediate process.

Recent increases in disk drive capacity and workstation improvements such as Intel's new E7505 chipset have made high bandwidth processing more affordable. Processor speeds have passed the 3GHz mark and are climbing, and multimedia specific extensions such as MMX and SSE mean that these systems can now accomplish complex manipulations of large amounts of data in real-time.
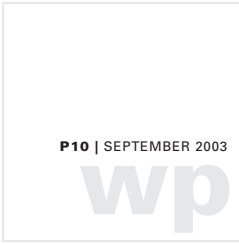
REPRESENTING FILM DIGITALLY
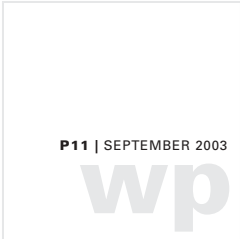
It is often said that using digital technology compromises the quality of filmmaking. While this is not strictly accurate there are several legitimate concerns. One of the main areas of concern arises from the technical limitations of various digital technologies as they relate to image acquisition, post-production, distribution and display. Another concern, albeit of a different nature, is that digital technology, by being more flexible, allows not only greater creative freedom but also greater compromise – particularly compromises on quality for reasons related to productivity and/or economy. However, digital imagery in itself is in no way constrained by such limitations.

Digital resolution

Digital images do not have the same physical limitations[13] as filmstocks and are therefore capable of resolving far more detail than even the finest grained stock.[14] A digital image can be created at any resolution and it is also possible to increase the resolution (number of pixels) of digital images indefinitely should more detail be required to represent the scene.

Digital film sensitivity

A real-world scene contains light (electromagnetic radiation) across an infinite range of intensity. However image-capturing systems such as the human eye or a camera (film or digital) cannot detect this infinite detail. Instead they are only able to discern relatively large differences in intensities. As a result what we, or the camera, sees is only a small sample of what is really in the scene[16]. The Director of Photography has to ensure that enough detail is recorded, and that the right detail is recorded, so that when the human eye sees the recording later on in the cinema, the desired effect is obtained.

Digital images however are capable of representing an almost infinite range of light intensities. 32-bit formats can distinguish between nearly 4.3 billion different levels of intensity. However since cameras and scanners cannot record such detail, it is more common to use 10-bit formats like DPX to represent scanned film. This has a much lower sensitivity[17] but is much more efficient to process.

Digital Image Resolutions

2K	2048x1556	82 pixels/mm*
3K	3072x2334	123 pixels/mm*
4K	4096x3112	164 pixels/mm*
8K	8192x6224	328 pixels/mm*

Listed above are several possible image resolutions that can be used for full aperture 35mm digital film. Resolutions like 8K are rarely used except for some specialized production needs – such as digital matte paintings, visual effects plates or for formats like Vista Vision.

* Digital approximations to a film stock's MTF based on a 35mm full aperture exposure (exposed area of 25mm x 18.7mm). A 500T color negative that cannot resolve detail greater 100 cycles/mm can be fairly accurately scanned at 2K, However a 50D stock that can respond to detail of over 200 cycles/mm would be better represented by 4K or 6K scans – Note: many factors including film weave, motion blur, light intensity, exposure settings and contrast differences can all effect the resolving power of the same piece of filmstock.

Digital Image Density

8-bit	2^8 gradations	256 intensity levels[A]
10-bit	2^{10} gradations	1024 intensity levels
12-bit	2^{12} gradations	4096 intensity levels
16-bit	2^{16} gradations	65536 intensity levels
32-bit[B]	2^{32} gradations	4.3 billion intensity levels

The human eye is more sensitive to equal increments of light change at low intensities.[15] By using logarithmic sampling of a source intensity range, such as film density, a digital image can allocate more intensity levels to represent low intensity (shadow) detail. As a result 10-bit log sampling is often used to provide a more compact format with higher visual quality.

[A] Per color component – an 8-bit image represents 24-bits of RGB color information

[B] 32-bit, High Dynamic Range (HDR), images are capable of resolving more levels of intensity than the human eye or a silver halide emulsion will ever be able to. They offer filmmakers new creative choices including the ability to record a scene with different exposure settings that can then be stored as a single image. This allows the exposure of a shot to be modified later without losing detail in either the shadows or highlights. This is particularly useful for visual effects work.

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[13] The ability of a film to resolve detail is limited by the sensitivity of its silver halide emulsion as defined by each filmstock's modulation transfer function (MTF).

[14] It should be noted that limitations do exist in digital acquisition and scanning systems. These are imposed by the physical constraints of the CCD technologies used in these devices.

[15] The human eye tends to see 18% intensity as mid-gray (half way between black and white) – the mid-point on linear gradient from black to white tends to look almost white

[16] However, the human eye adapts to the scene seeking out regions of interest and analyzing them in more detail.

[17] DPX files are 10-bit and can record 1024 different levels of intensity. Since this is somewhat less than a filmstock, special (logarithmic) sampling is used to maintain image quality.

Working with digital film

Given some of the current limitations of digital acquisition technologies, film remains the best way to capture the most visual information from a scene. This introduces the thorny technical issue of how to best convert this information to its digital equivalent.

Answering the question of how film can be accurately defined and quantified in terms of spatial resolution and levels of light intensity is no simple task. It is a challenge in that the different and constantly evolving grain structure and photosensitivity of film emulsions makes defining a 'Gold Standard' a moving target.

This issue is further compounded when technology and/or economic constraints require lower data sampling and/or compression. This involves determining the optimal sampling for a given film exposure so as to retain enough data to represent the subtleties that are present in a piece of film, while reducing the amount of data captured to increase productivity.

As mentioned above, the resolving power of a digital image is limited only by the deliberate compromises made during acquisition and for cost-effective production. These compromises are generally made in order to increase productivity since the larger the image, the longer it will take to process in the computer. Given that we can create digital intermediates at various arbitrary resolutions, how do we choose which resolution to choose and what should the compromises be?

There is no single answer. The resolution should be a function of the production requirements. Ultimately the biggest limiting factor will be the scanner. But whether the scanner should be set to 2K or 4K or whether you should then convert the image to 3K or 1K are all considerations that will depend on the desired result. Modern digital film workflows use digital images of a variety of sizes and formats depending on their use, but the most popular format by far is the 10-bit DPX format and the most frequently used resolution is 2K. However, for complex visual effects work, larger resolutions and bit-depths are often used to prevent image deterioration during processing. 2K 10-bit DPX files are popular as they provide an excellent compromise, retaining as broad a dynamic range as possible while maintaining a relatively small file size. When compared to the original negative, some data is lost since a 2K 10-bit file is roughly equivalent to a filmstock with a modulation transfer function (MTF) that hits zero response at 80 cycles/mm and has very limited sensitivity (1024 shades of grey) – a level of detail far exceeded by most filmstocks today.

In fact, given that most filmstocks only start to have significantly less than a 10% response to details over 200 cycles/mm, a 6K scan (capable of resolving 246 pixels per mm) would be required for a more precise representation. The article reproduced on the following page, with the kind permission of Editors Guild Magazine provides some interesting insights into these issues.

Image and color fidelity

One of the key hurdles identified repeatedly by early implementers of digital film workflows is the problem of maintaining image and color fidelity from acquisition to final screening. The difference between looking at an optical and a digital projection of the same image can be immense and calibrating the two together is a challenge. Without accurate calibration, it becomes difficult to predict how changes made to the digital image will look when printed back to film. This increases the difficulty of matching digital prints to lab-processed prints. Calibration is particularly important when grading films, where the bulk of the changes made to the image are related to color. This requires an accurately calibrated environment where the impact of changes can be judged with confidence.

More importantly digital grading solutions must be able to emulate what happens within the laboratory so that digital prints can be inter-cut with lab processed prints if desired. The most successful grading systems are those capable of working in logarithmic colorspace (filmspace) and that can be accurately calibrated to each individual lab's printing processes (printer light calibration).
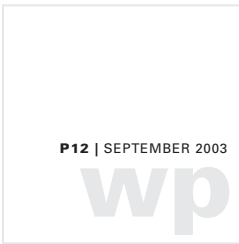
Digital Intermediate for Film

Scanning film takes time, and time is money. The result is that filmmakers and vendors must make choices about how much data is scanned from each frame. This number, the scan resolution, influences the economics of the entire process. Scans are measured in thousands of pixels of horizontal resolution. One "K" means 1,024 pixels. A full-aperture "4K" scan has 4,096 pixels horizontally, and 3,112 pixels vertically. 4K is the current gold standard, and it's intended to faithfully record every single detail of the underlying film. 2K scans are less expensive and more common: 2,048 x 1,556 pixels to each frame. They yield files that are only a quarter the size of 4K scans: about 13 MB vs. 52 MB per frame.

How do these resolutions compare to film? Theoretically, based on the grain structure of the emulsion, film could be pegged as high as 6K. Practically, however, this is only true for first-generation camera original and only under ideal conditions. In practice, negative film is typically assumed to have a maximum resolution of about 4K. Release prints from an internegative, depending who you talk to, are said to have a resolution of well under 1,800 pixels across, and the projected image may actually be worse because lamps can be misaligned, and lenses can be dirty or out of focus.

4K and 2K scans can be made in film scanners, which are dedicated devices with traditional pin registration. This is a relatively slow process: one frame every 3 to 12 seconds. Scanning a 100-minute feature this way can take more than a week of round-the-clock scanning. That's why some houses are using devices based on high-definition telecine technology. The most common is the Spirit DataCine, made by Thomson Multimedia, which bought the technology from Philips. They scan much faster, at about six frames per second, which brings down the time to scan a 100-minute show to a much more reasonable seven hours or so. This kind of speed helps make the digital intermediate process affordable.

The DataCine makes scans at 1,920 x 1,440, which is just under true 2K. To fill the standard 2K frame, these scans have to be up-sampled, which entails the risk of degrading image quality. What's more, the DataCine samples color more coarsely than a conventional scanner. Theoretically, this means that DataCines make slightly inferior scans, but the difference can be subtle, and their cost advantages make them appealing in many environments.

What is the right scan size for digital intermediate? Purists say that 4K is the only way to go. But many people say that 2K is more than good enough for theatrical distribution, since it offers as much or more resolution than the film prints we're seeing now. By the time you read this, three new digital intermediate shows should be in theatrical release: We Were Soldiers, scanned at true 2K by Efilm, and two films transferred on DataCines: Hart's War out of Cinesite, and Panic Room done at Technicolor's digital facility, Technique…

Digital intermediate technology is evolving quickly, and prices are expected to come down as new and faster equipment becomes available. Thomson is currently developing the Spirit Datacine 2, to be released in October. It is said to make true 2K scans in 14-bit RGB at a rate of 30 frames per second, as well as 4k scans at 6 to 8 fps. Other high-speed, high-resolution scanners are in the works from Sony, Cintel, ITK and others. In addition, Kodak is developing a digital projector that will be capable of showing true 2K images — at about half the cost of today's digital projectors with pixel dimensions of only 1,280 x 1,080. This may create a de facto standard of 2K for digital cinema theatrical distribution. The digital intermediate process should fit into that nicely.

In an environment where video acquisition is starting to make inroads in feature production, digital intermediate offers a new lease on life for celluloid, giving filmmakers many of the creative tools that their TV counterparts have used for years. At the same time, the process takes us one step closer to a full digital workflow where all circled takes are scanned and a cut show is built entirely in the digital domain. Though we're not quite there yet, as prices come down, some type of digital intermediate process may soon seem like a creative no-brainer for any show that will be released on film.

Rainer Standke, 'Digital Intermediate for Film', Editors Guild Magazine, Vol. 23, No. 3 - May/June 2002.
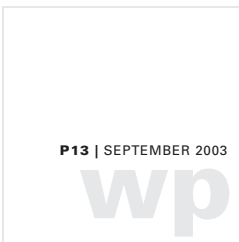
Calibration

Digital systems for looking at scanned images consist of various graphics processing hardware and display devices, from computer monitors to DLP projectors. These devices introduce a myriad of variables to the color calibration process, and technical limitations (such as the inevitable color drift of devices like CRT monitors) can create significant challenges for filmmakers.
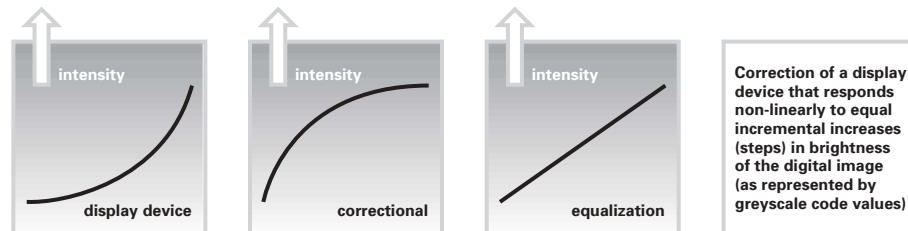
Due to the nature of color grading, the majority of these issues become extremely critical when attempting digital color timing. Currently, most facilities that have adopted a partial or full digital intermediate pipeline have devised their own, facility-specific methods of ensuring that image fidelity and quality is maintained at every point in the process. Their effectiveness in doing this has allowed them to build trust with their clients.

Most digital grading facilities are set up so that the digital image is both displayed on a computer monitor and projected on a screen. The screen projection allows both the color timer and the director of photography to make interactive changes and immediately visualize the impact of those changes in an environment that will closely resemble that of the final projection.

However, in order for a digital grading solution to be successful it must be possible to accurately calibrate it. For example, reds displayed in the RGB video colorspace standard on most monitors, look completely different after having been printed to film

Modern digital grading provides accurate calibration tools that are easy to set up. Facilities with their own color calibration technologies can customize the system to meet their specific needs, but smaller facilities can use intuitive calibration steps to set up an accurate display environment.

Basic calibration commences with the linearization of the display device to avoid distortion of the film color look up tables (LUTs) that will later be applied. This is done using a light sensitive device[18] to measure the intensity of various gray patches that are either displayed on the monitor or projected on a screen. A correctional LUT is produced that ensures that the display intensity responds linearly to the values of the image – i.e. that the CRT or projector intensity increases in proportion to the color values of the digital image. The white and black points also need to be set if the device is to accurately represent the white and black (fully transparent and fully opaque) characteristics of film. White is normally set to specifications based on open gate and clear film projections.

intensity

display device

intensity

correctional

intensity

equalization

Correction of a display device that responds non-linearly to equal incremental increases (steps) in brightness of the digital image (as represented by greyscale code values)

The next stage is to calibrate the digital pipeline and create a look-up table that will accurately emulate the look of film on the digital display device (both the CRT and the digital projector). Today this process is not well automated, although new technologies are emerging from companies like ARRI and Kodak that will make it easier to do so.

Given the amount of variables that come into play when choosing a stock and processing it through a laboratory, it is recommended that the digital grade be calibrated to match the laboratory that will process the film. Calibration can be accomplished using film wedges and tools such as Kodak's Laboratory Aim Density (LAD) control system. The whole digital intermediate pipeline needs to be calibrated from scanner to printer.

Scanners can be calibrated by scanning test negative – either by shooting test cards and wedges, or by ordering LAD color negative from Kodak. Often a scanner will be re-calibrated for a particular project or reel since the DP may have deliberately chosen to shoot in a way that does not fit well into previous calibrations.

[18] Although an X-Rite device is supplied with systems like Discreet's **lustre**™ other devices such as the CS-100 Minolta probe can be used.
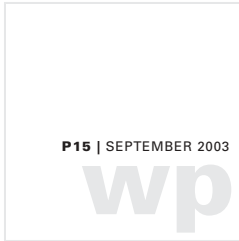
Calibrating the film printer is equally important and is accomplished by printing either test wedges or Kodak's digital LAD file to negative and having it developed by the laboratory. A print can be made for review purposes and the developed negative can also be scanned back into the system to close the loop on the calibration. The rescanned negative is compared with the original file. Significant differences often indicate a problem in either the printer or scanner calibration settings or in the lab processing.

Once the scanners and printers are well calibrated, a piece of film scanned into a digital file, printed back to film and cut back into the original negative should be indistinguishable from that negative[19]. If this is the case the digital intermediate pipeline is well calibrated and no distortion of the image is occurring as it goes through it.

The final stage is to calibrate the display devices so that the image going through the pipeline can be seen more intuitively. A film look-up table (LUT) is therefore created to simulate the look of the projected film.

This film LUT is used as a display tool and is not part of the digital image. Changing the calibration of the scanner and printer modifies the properties of the image itself, whereas calibrated display LUTs are designed to leave the digital image intact. Instead they simply enable a modified version of the image to be displayed on a digital device; a version that is more representative of what the film print will look like when projected optically.

Display LUTs are an essential part of any digital grading system since they allow the cinematographer and colorist to accurately determine how changes they make will modify the final print – they provide the "what-you-see-is-what-you-get" aspect to the system. In this way a Director of Photography can see how the grade is progressing as if he/she were viewing an answer print. The display LUT provides the translation of the digital file into a display that has the same color and light characteristics of film.

Professional color grading systems are capable of loading multiple display LUTs depending on the requirements of the grade. In this way different display LUTs can be loaded and be created for different projects, different negatives, different print stocks, different laboratories and of course different display devices. Since digital grading systems are so intimately involved with the look of a film, it is also essential that they can be calibrated to the specific processes of each laboratory. Basic printer light grading that accurately matches that of any given laboratory is an essential feature of any digital timing system. Different labs use different printer settings for 18% gray (such as 25-25-25 or 30-30-30) as well as different numbers of printer points (lights) per f-stop. Professional grading solutions therefore offer the ability to customize printer light settings to those of a lab.

These printer settings are obtained from the lab chosen to do the printing and input into a setup file. They ensure that when the director of photography is timing a film digitally, the digital grade can be matched to the lab grade. This is essential for basic grading as it helps maintain consistency and allows digital systems to interact better with the laboratory environment. It also provides a more intuitive way for film professionals to do the bulk of a film's grading before embarking on more complex creative tasks.

Arri

Companies like Kodak and ARRI have developed systems that enable digital intermediate pipelines to be accurately calibrated from scanning through to printing.

ARRI have developed their L*a*b (L=Lightness; A=red-green axis; B=blue-yellow axis) system based on the ICC color standard and a software application called "Alice" that allows the image to be correctly viewed on a computer workstation, before going to print.

The ARRI system matches the color space of the video display to the corresponding color scheme for film so that the ARRILASER, which is used to print either an internegative (IN) or interpositive (IP), will accurately reproduce all color grading, and color matching information.

The ARRI f-theta lens solid state laser is capable of printing to film at 3.2 secs/frame at 2K, and 4.9 secs/frame at 4K. With lab sized magazine capabilities (2000 ft. reels) the ARRI need only to be reloaded every 24 hours, limiting the amount of human supervision required and allowing long production runs. The ever improving speed of these technologies is a powerful enabler for the digital intermediate process.

[19] In reality there will always be slight differences depending on the precision of the process. The key is to make sure that these differences are not readily seen in a typical viewing conditions

Film scanning

Digital film workflows became reality in the late 1980s with the development of new systems for both scanning and printing film. At the time, film scanning and printing was both highly specialized and extremely slow; equipment was expensive and required considerable technical expertise to maintain. As a result, early scanners and printers were owned and operated by large, specialized visual effects companies such as Industrial Light and Magic, the Computer Film Company, and Cinesite, a division of Kodak. Other post-production companies outsourced their scanning to these companies.

Although telecine devices have been able to scan film in real-time for decades, they produced video quality images and lacked pin registration for consistency [20]. For these reasons it was not really possible to use telecine devices for scanning projects destined to be printed back to film – or at least not if maintaining image quality was a concern. [21]

In the late 1990s, a new generation of high-resolution telecine devices such as Thomson's Spirit was developed. These new devices were initially targeted at HDTV production but were of sufficient quality to be used on various film projects. Their manufacturers saw an opportunity to expand their market and soon developed 2K data [22] versions. Although these devices still lacked the quality [23] of flatbed film scanners they quickly became popular due to their attractive price performance ratio [24] and ease of use. This opened the door to scanning to a wider range of post-production facilities.

Today there are several hundred facilities around the world capable of scanning film at high resolution and the top post-production companies now offer clients who shoot on film the possibility of finishing at film (2K) resolutions – and thereby obtaining a higher quality product. As with D1 production for video, 2K data helps maintain the quality of the original film throughout the post-production process.

Digital grading

Until recently there has tended to be a one-to-one correspondence between scanning devices and hardware color correction systems. Telecine and color correction suites are often the same room and the two are often perceived as a single unit — a solution that has proved highly efficient for videotape environments.

On the other hand, the first color correction systems for film were visual effects software applications such as Kodak's Cineon system. These offered an advantage in that multiple systems could work in parallel to simultaneously process images coming from a single scanner. The one-to-one correspondence was temporarily broken.

Unfortunately, early digital grading workflows such as the one used at Cinesite could not be widely adopted due to the limitations in computer performance, network bandwidth and affordable storage capacity that existed at the time. As a result, hardware solutions based on the established telecine paradigm gained brief popularity, although they lacked the flexibility of data based systems.

Today computers, networks and data storage are both faster and cheaper, and a new generation of more powerful software grading systems is appearing on the market. These solutions offer real-time performance, high levels of interactivity and sophisticated features, yet they are purely data-centric. This allows them to fit more efficiently into digital film production pipelines and to collaborate more effectively with other areas of digital post-production, such as visual effects.

Hardware-based grading systems tend to be expensive to build and somewhat inflexible in their deployment, whereas software grading systems can reduce overall installation costs while increasing productivity. For the same capital expenditure several creative seats can be used in parallel, and therefore significantly reduce production times.

[20] Pin registration is a technique for accurately aligning a piece of film in a device (scanner, printer, camera etc.) using the perforations alongside the outside edge of the stock.

[21] Of course many movie theatre commercials are video quality sources printed to film, as were some types of film projects (e.g. *The Blair Witch Project*).

[22] HDTV samples a film frame at 1920x1080 pixels with 8-bit or 10-bit 4:2:2 sampling per pixel. This can then be up-converted to 2K on some devices, or for better quality the image is sampled as 2K (2048x1556) with 10-bit 4:4:4 sampling per pixel.

[23] These scanners often use lower quality components than high-resolution film scanners, have higher signal to noise ratios and produce color variations when sampling the same portion of film twice. They also lack pin registration causing the film to weave and jitter as it passes through the gate and rendering it difficult to scan the same frame in exactly the same way twice.

[24] Quality pin registered film scanners scan at several seconds/frame whereas telecine scanners scan at several frames/sec – today some scan in real-time.

THE DIGITAL INTERMEDIATE PROCESS – A CLOSER LOOK

There are many digital intermediate workflows used to produce feature films today, but they can be grouped into three distinct categories depending on the complexity of (post) production tasks the digital intermediate is put to.

Single purpose workflows

The most basic digital intermediate workflows are those that serve a single, or limited set of purposes. They may be used almost exclusively for grading, or for visual effects work, but not a lot of other processes are attached to the digital files. More and more, these workflows are being developing into more complete digital pipelines.

These simpler workflows offer film laboratories and post-production companies the ability to access a host of new creative tools without having to worry about managing a complex digital production pipeline. They still have distinct advantages over traditional film processes in the scope and quality of the results they produce. They provide huge freedom when it comes to color correcting a film or designing a look that is difficult or impossible to create on set or on location. Films such as the Coen brothers' *O Brother, Where Art Thou?* were graded in this manner.

Partial digital workflows

The power of the digital intermediate process can be increased significantly when the workflow is expanded to include multiple digital processes in a single pipeline. This way multiple creative processes can use the same digital files. Images can be scanned once and then sent to multiple locations for different tasks (such as grading, dust-busting or visual effects). However since parts of the post-production workflow are still done using traditional film techniques, these workflows are only partial. The bulk of modern film post-production belongs in this category, although a few films such as George Lucas's *Star Wars Episode I and II* and Peter Jackson's *The Lord of The Rings* trilogies have come close to being full digital workflows. For *The Lord of the Rings: The Two Towers*, supervising digital colorist Peter Doyle and first assistant editor Peter Skarratt, put together a unique digital intermediate workflow where section by section, the entire film was conformed, graded and held as digital files for visual effects work. As a result, the entire motion picture, with its roughly 3,500 edit points, had only 600 negative splices in it.

Full digital workflows

In a full digital pipeline each and every element destined to be in the film is stored digitally and the instructions describing all creative decisions (editorial, conform, visual effects, color grade, dust busting) are conserved as separate metadata files. These instructions may have to be rendered or 'baked' into the media files to complete the process. but they offer a level of abstraction and communication that makes later revisions/versioning faster and facilitate better collaboration.

Today, the best examples of film productions that use fully digital post-production workflows are CGI animated features such as those created by Pixar. However, as mentioned previously, several feature films have come close to fully digital (post) production methods, and that number can be expected to increase with time.

Digital software

The great advantage of digital post-production is the ability it provides to accomplish creative tasks that were not previously possible – as has been clearly demonstrated by the scope of CGI and visual effects work today. This is equally true for color grading, where a new breed of software solutions are allowing filmmakers to be more creative. The huge advantage of these new software solutions is the fact that they can be easily customizable, such as the Colorfront technology used at EFILM Digital Laboratories, and more productive than hardware solutions. Software solutions have no dependency on customized hardware for processing and offer richer, more quickly evolving feature sets. They often offer equivalent performance, and can be deployed more flexibly.
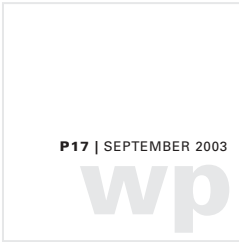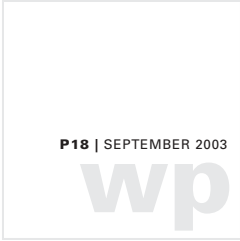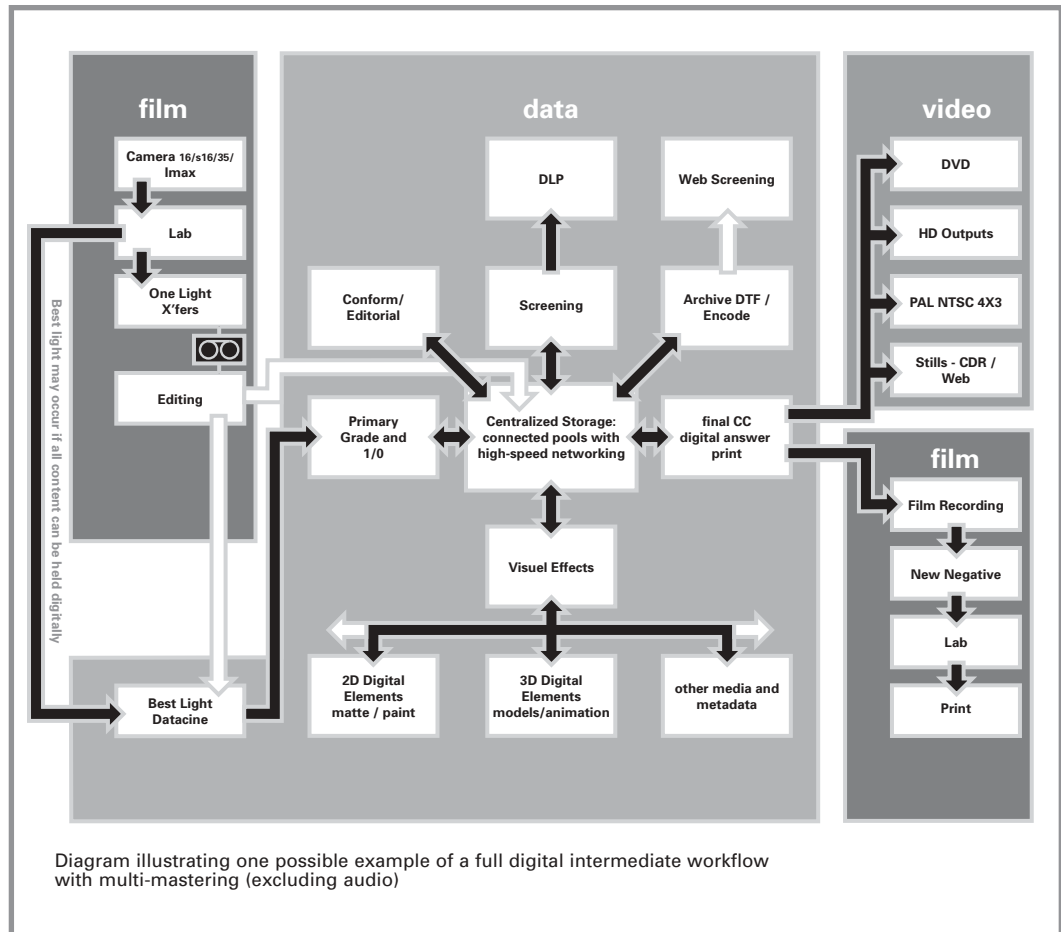
One of the great advantages of software-based pipelines is that they can efficiently parallelize complex tasks and divide them between multiple workstations instead of having to process them sequentially on a single system. This is the concept behind all modern post-production where resources need to be shared and highly scalable.

Grading is often a task where the pressure to be creative is only equaled by the pressure to get the job done quickly. Dividing the tasks between multiple stations is an effective way of increasing the overall throughput of the facility. The ability to store all changes, or corrections as a soft set up, instead of actually manipulating the image data, results in a process where all creative changes can be modified at any time right up until the final print needs to be made.

Today, 16-bit/component image processing can be carried out in real-time on 10-bit 2K RGB files without custom hardware acceleration, a testimony to the inexorability of Moore's Law. 2K hardware systems developed as little as a year ago are already being bypassed by software solutions that offer comparable performance but can offer a much broader feature set. It is for reasons like this that an ever increasing number of feature films are being graded using software technologies such as that developed by Colorfront, which is used to process nearly half of the digitally graded films in the world today.

Colorfront technology is used to process nearly half of the digitally graded films produced in the world today


Diagram illustrating one possible example of a full digital intermediate workflow with multi-mastering (excluding audio)

Digital grading software systems provide a highly flexible means of working with digital intermediates. They can be scaled easily and deployed in a variety of different forms. The Discreet **lustre**™ system, also based on Colorfront technology, can be deployed as either a Master Station or as an Assistant Station. The Master Station provides the interactive grading environment, whereas the Assistant station can be used for labor intensive and non creative tasks, such as dust busting or conforming. The flexibility of the software architecture allows high resolutions such as 4K or 6K to be processed using a render farm while grading is carried out interactively on 1Kor 2K proxies.
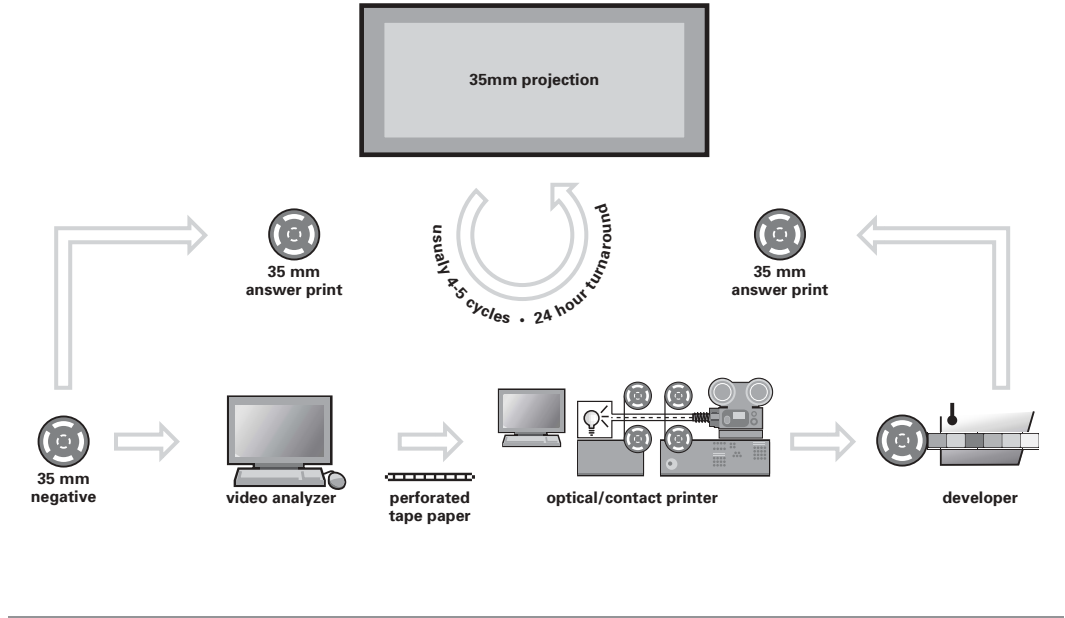

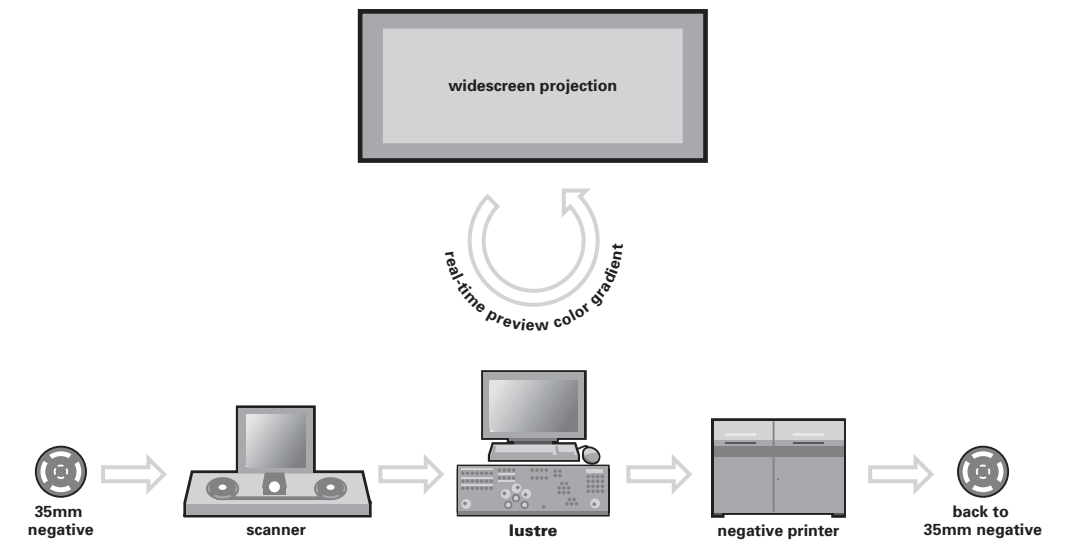Diagram illustrating a typical collaborative digital grading environment
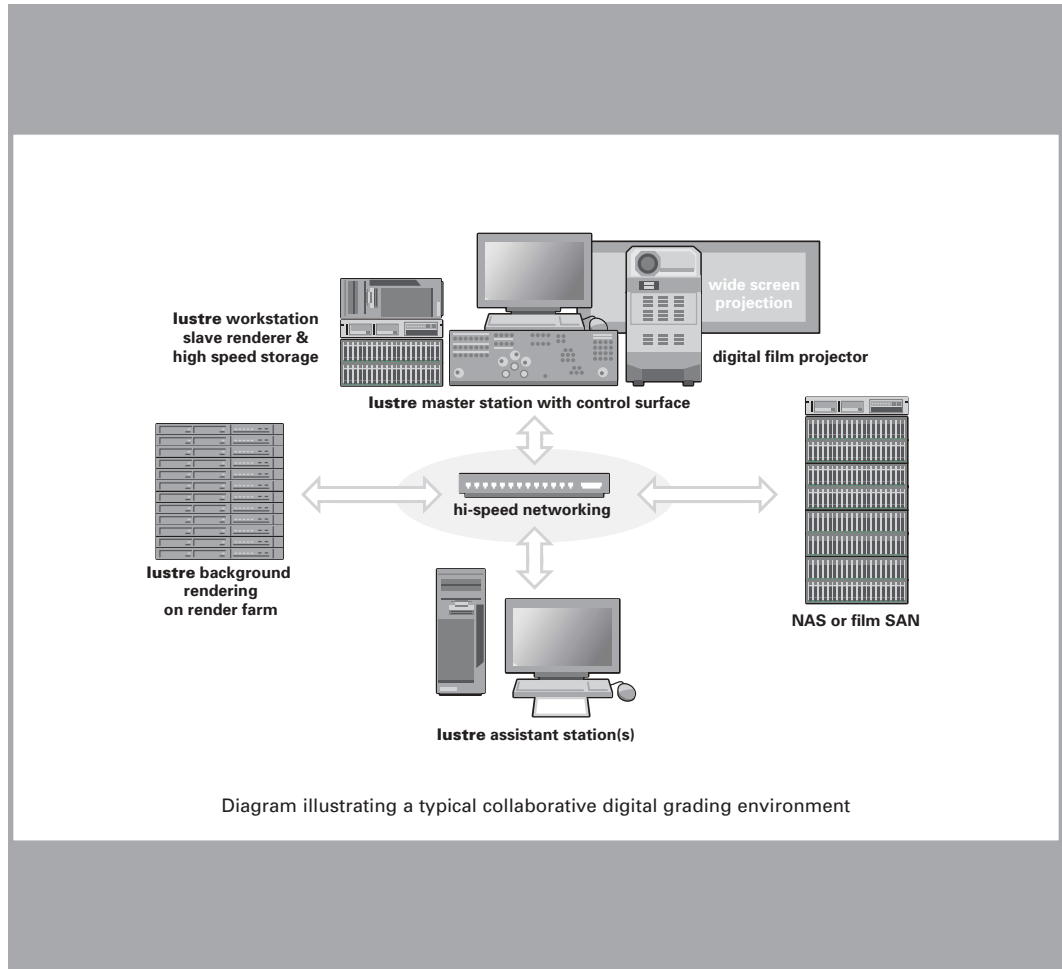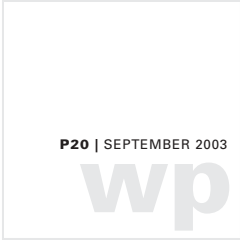
A key advantage of color grading and timing digital intermediates is the immediate feedback they provide. Instead of having to wait 24 hours to view a print, the director of photography can ask for changes to be made to the film and see those changes projected onto the screen immediately. Whether simply adjusting the red, green and blue printer lights or creating complex visuals, feedback is immediate and interactive. Unlike optical grading, the DP can ask for changes while viewing the digital equivalent of an answer print projected on screen. This provides a high quality environment for the DPs to provide real-time feedback, enabling them to work in collaboration with the digital colorist in ways that are not possible with a lab timer.

traditional workflow

35mm projection

35 mm answer print

usualy 4-5 cycles • 24 hour turnaround

35 mm answer print

35 mm negative

video analyzer

perforated tape paper

optical/contact printer

developer

digital workflow

widescreen projection

real-time preview color gradient

35mm negative

scanner

lustre

negative printer

back to 35mm negative

THE FUTURE OF DIGITAL FILM

Digital acquisition

Digital capture has been part of the world of television and video for more than a decade. The lower spatial, temporal and color resolution of analog video equipment paved the road for a much earlier and easier digital transition. The same has not proved to be the case for film, which is capable of capturing far more detail than current digital camera technologies. Today film can resolve far more detail in terms of spatial resolution, light intensity and temporal changes (high speed photography).

Digital video formats such as Digital Betacam, D2, D3, HDCAM and D5, while adequate for TV image reproduction, have too limited a dynamic range or are too reliant on compression to be effective as a high-end replacement for film. They cannot capture image information at high resolution without aggressively compressing the data, which limits their suitability as a high quality digital film master.

New digital technologies are being introduced today that can capture high-resolution images as uncompressed RGB data and store them directly to disk (as opposed to videotape). They offer new options to filmmakers in terms of overall speed, image quality and flexibility. When combined with the emerging standardization of archive and storage formats, it would appear that digital capture may play a significant role in the future of production.

High definition digital cameras such as SONY's HDCAM SR and Thomson's Viper FilmStream are already being tested in the field and new 2K data cameras such as Dalsa's Origin seem capable of capturing images of even higher quality. These cameras show a lot of promise for the future of high-resolution digital acquisition and it is anticipated that they will grow in popularity over the next few years. However, they are still far from being able to completely match film cameras. Digital cameras, even high resolution ones like the Origin, cannot replace film cameras on many kinds of film shoots. Their response times are significantly slower than film cameras which are capable of shooting at very high frame rates (slow motion photography), and film stocks still offer greater resolving power than 2K cameras – it is clear that digital acquisition and film acquisition are set to co-exist for many years to come.

Digital cameras like the Viper do not react to light in the same way as film does, and the images they produce look distinctly different to film. They cannot simply be printed to film and graded in the lab, but rely on digital grading systems to help create the final look prior to film printing.

Based on customer interviews conducted by Discreet in the second half of 2002, the majority of content creators who predict that digital camera technology would be successful also suggested that its adoption would require color grading as a post-production process more than ever before.

In fact, they anticipate that directors of photography may actually decrease the amount of on-set 'tweaking' they do as they become more familiar with (and confident in) the creative possibilities of doing this digitally. The general perception is that there will be a move to capture as much 'flat' data on-set, and use post-production color grading and special effects to create the exact mood.

Although such a trend is still somewhat speculative, it is becoming clear that the cinematographer's role in digital filmmaking is expanding as these new tools become available. The importance of managing the aesthetic aspect or "look" of a film is as critical as before, but has become more complex as the number of options and creative choices has increased, thereby reinforcing the need for skilled cinematographers who can navigate the complexity of modern filmmaking and ensure that the final product meets the aesthetic desire of the director.
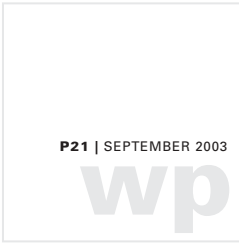
Digital video

Digital video formats (DV, Digi-beta, D1, HDCAM, etc) are generally considered to be too limited in capacity to accurately store and transport high-quality film images. As a result, data from digital cameras is often recorded directly to disk, sometimes using dual link SMPTE 372M video technologies, and archives saved to data tape devices such as DTF and DLT.

Some devices such as the Panasonic D5 recorder use less compression and are used for many digital cinema productions based on HDTV pipelines. However, there are new technologies on the horizon that may facilitate wider adoption of videotape devices in filmmaking. For instance, Sony recently introduced its HDCAM SR technology and a new HD VTR (the SRW-5000), capable of storing color data 4:4:4 sampled at 10-bit/component and with much milder compression than HDCAM. In addition to real-time video I/O (video in and out) streams, the deck has been built to support a TCP/IP interface for digital data transfers, potentially ushering in the era of affordable hybrid video/data recorders.

We can expect similar future advances in technology continuously improving the flexibility, price, performance and quality aspects of digital systems and facilitating increased adoption of digital acquisition and production for both HDTV and cinematic release.

Digital cinema

Proponents expect an eventual transition to digital cinema projection, and say the real question is not "if" but "when." One thing is for certain, film projections are likely to be around for many more years to come. While digital film projection would be likely to prompt increased adoption of digital intermediates in production, the two are not linked. The digital intermediate process is independent of how the media is acquired and distributed, and is used because it offers unique advantages to post-production. There are currently only a few hundred digital projectors installed in movie theatres worldwide. Digital screening capabilities are expensive to install and maintain, and movie theatre margins are generally too low to justify the additional expense. Moreover, the bulk of the cost savings that can be generated by migrating to digital systems lie in the production and distribution of cinema products, not in display. Industry organizations like NATO (North American Theatre Owners) continue to monitor the progress of digital technology, but have reservations in recommending widespread adoption – mainly due to concerns about the cost, quality and lifespan of current digital systems.

Digital projection systems capable of lighting up a large screen are still significantly more expensive than optical systems. More importantly, optical projectors are inexpensive to maintain, are fairly simple to setup and face less risk of obsolescence. Theatre owners are somewhat fearful that (1) digital systems are technically difficult to maintain and setup, and (2) new formats, standards and better technologies can quickly make today's generation of systems incompatible and obsolete.

Digital systems continue to improve in quality and there is some momentum gathering behind high-definition digital displays outside of cinemas. Texas Instruments is developing 2K DLP technology which is being used in new projectors from manufacturers such as Barco and Christie.

Producing and distributing release prints is hugely expensive. Thousands of prints need to be shipped to the world's 150,000 screens. As a result, it is estimated that $1 billion/year[25] can be saved simply by eliminating the need to use physical prints.

There are a number of companies vying for control of the distribution and playback of digital cinema content. They are preparing dedicated, secure networks (either terrestrial or satellite[26]) capable of moving high-resolution content to the theatres in reasonable time periods and with guaranteed security. Unauthorized duplication and piracy is a huge concern for the movie studios and another gating factor to the widespread adoption of digital cinema.

[25] ERIC A. TAUB, Among Film's Ghosts, Its Future, New York Times: http://www.nytimes.com/2003/06/19/technology/circuits/19cine.html
[26] Today, a single satellite transmission can reach thousands of theatres at a time and at costs of less than $1000/hour.
   It can take roughly 2-3 hours to transmit a 90-minute feature

Digital intermediate solutions

Digital intermediates place stringent demands on post-production and it is sometimes difficult to look beyond the technical aspects of managing large amounts of data to the ultimate reason why digital intermediates are so compelling – their ability to empower new levels of creativity.

Over the last decade two basic models have been developed to deal with the issues of creative digital post-production. These can be loosely defined as the hardware and the software models[27].

The hardware model comprises system manufacturers who invest most of their research and development effort in building proprietary hardware systems to accomplish specific tasks. Within this model, various approaches are possible including the development of ASICs (Application Specific Integrated Circuits) and the programming of FPGAs (Field Programmable Gate Arrays). Both are designed to 'bake' specific post-production tasks into customized hardware.

The software model is preferred by companies that specialize in developing creative tools rather than platforms. These companies invest the bulk of their R&D effort into developing feature-rich applications designed to run on generally available computer platforms under the assumption that Moore's Law tends to rapidly render most hardware platforms obsolete.

It almost always takes less time to develop and revise software features than it takes to implement them in hardware. Software products therefore tend to be richer in functionality and evolve more quickly. On the other hand, hardware models can offer a temporary performance advantage. The more specialized the system the greater the advantage but the more restricted the product's feature set will be. The best hardware systems are those that are highly optimized for a few specific tasks. The broader the feature set a manufacturer tries to implement in hardware, the more the system will resemble general purpose computers and the less of a performance advantage it can offer. Companies like SGI, AMD and Intel invest billions of dollars developing high-performance general purpose computing platforms, which makes it all the harder for custom hardware manufacturers to keep pace.

From 2000 to 2002 custom hardware manufacturers were able to offer a performance advantage in 2K image processing. This advantage was significantly reduced with the release of several new high performance computing platforms towards the end of 2002, which enabled high-end software solutions[28] to offer real-time 2K for the first time.

Today hardware and software models offer equivalent performance for 2K digital intermediate workflows[29] and the real performance differentiator has moved up to 4K – although no manufacturers of grading, editing or effects systems currently offer 4K hardware solutions.

Ultimately the selection of a hardware or software solution will depend on the exact requirements of the post-production facility. Those requiring the greatest flexibility in terms of scalability, collaboration and data management or those looking for more complex feature sets in order to enhance their creative capabilities will tend to invest in software solutions. Given the rapid evolution of both computer technology and the digital intermediate process, it can be reasonably expected that color grading will evolve in a similar way to other parts of the digital film pipeline which, for the reasons above, have come to be dominated by software based systems.

[27] This section is analyses at the use of specialized hardware for 'creative tasks' – visual effects, editing, color correction – which is a distinctly different paradigm to the use of hardware for facility infrastructure - scanning, printing, video – and productivity tools – standards converters etc.
[28] Software solutions like the lustre system developed jointly by Discreet and Colorfront are capable of realtime 2K image processing at 16-bit/component using the CPUs of the host computer – a more flexible approach than developing custom ASICs or programming FPGAs to deliver the same performance.
[29] As of early 2003, tuned software systems were able to match the performance of many general purpose 2K custom hardware platforms, although highly specialized hardware systems like the da Vinci 2K continue to offer better performance for some tasks. It is anticipated that this gap will narrow fairly quickly.

Is 2K good enough?

As discussed in the chapter entitled Representing Film Digitally, there is some debate as to whether a 2K scan is the perfect resolution for digital intermediates. Today 2K is definitely a more practical data size but it has some definite quality limitations.

Not only is a 2K scan practical but it is quite capable of providing a high quality digital representation of a release print, especially when the final viewing quality of the majority of release prints is taken into consideration. On the other hand 2K scans cannot adequately capture all the richness of detail contained on the original camera negative. For this higher resolution and higher bit-depth scans are required.

The question whether a 2K scan is good enough can therefore be transposed into the question of whether a digital intermediate should really be a high quality representation of the original camera negative or of the release print – i.e. whether the image quality should be a function of what is captured on set, or of what is displayed in the movie theatre.

Most film professionals would argue that, given identical costs, keeping the quality of the original negative throughout as much of the production process as possible is preferable; in much the same way that digital video post is based on maintaining the quality of the original source right until the end of the process. Only at the end is it converted into the low-resolution (composite or MPEG) signal that is sent to the viewer.

Today 2K scanning is a reasonable compromise. The resulting image is of sufficient quality for most post-production needs and the productivity gains are significant. However, this should not be expected to remain the case forever. Some parts of the digital post-production process already use much higher resolution scans, the most obvious being 4K scans for visual effects. Today such high resolution scanning is only carried out on an as needed basis since processing an entire digital intermediate at 4K is both expensive and time consuming. As the computer performance and storage capacity that can be purchased per dollar invested continues to increase, it is reasonable to expect that over time the digital pipeline will evolve to match that of the original negative in terms of quality and 4K or higher scans become commonplace.

Networks and storage

Digitizing an entire feature film at 2K creates a huge amount of data, which then needs to be managed throughout the digital intermediate process. Post-production companies invest a lot of time and money into managing this digital data, deciding what data should be kept online and where, what should be stored near-line, what should be archived, and where the data needs to go next in the production process.

As a result it is anticipated that the most successful digital intermediate workflows will be those based on flexible configurations of high-speed networking and cost effective storage.

The most popular networking technologies in use today are HIPPI and Gigabit Ethernet. HSDL (High Speed Data Link) is also gaining in popularity as a means of transferring high definition media as a point-point solution. Although HSDL offers some advantages in terms of performance, its use is limited in that it is not a pure data model. The long-term viability of technologies like HSDL is uncertain as new ultra-high bandwidth networking technologies such as 10 Gigabit Ethernet become more readily available and affordable.

Having to transfer data from system to system is another major concern since each transfer of the film means moving terabytes of data across the network, as a result facilities are investing in shared storage solutions that can help reduce the need of transferring data.

Several types of shared storage solution exist, the most scalable of which are Network Attached Storage (NAS) and Storage Area Networks (SAN). These differ in that a SAN is a dedicated network for storage devices, usually built on Fibre Channel technology, whereas NAS devices reside on standard networks (LAN or WAN) that may also be used for non-storage related data transfers.

SANs behave very similarly to direct attached storage devices. They generally rely on a specialized file system to provide access and therefore tend to be less versatile in that they may not be accessible by all operating systems. However the dedicated network can often provide additional performance not available on a NAS.
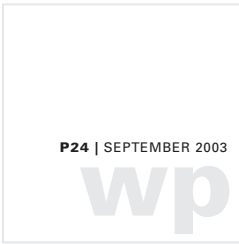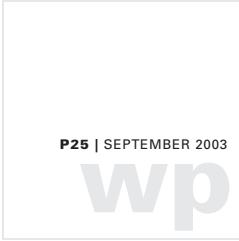
SAN solutions from some vendors, such as SGI SAN Server™ and CXFS SAN file system, have been specifically designed to provide high-performance data sharing between applications and have been installed at several digital film sites, including EFILM Digital Laboratories and Éclair Laboratoires, where multiple digital intermediates need to be processed concurrently.

NAS solutions consist of individual storage units that are attached to a TCP/IP network such as Gigabit Ethernet via a server. They are accessed using standard CIFS (Common Internet File System) and NFS (network File System) I/O protocols and are capable of serving data to multiple workstations runing different operating systems.

NAS solutions are relatively easy to manage and highly expandable. They benefit immediately from new network technologies such as Gigabit Ethernet and 10 Gigabit Ethernet and offer a high level of fault tolerance. High performance NAS systems like Maximum Throughput's Sledgehammer are particularly optimized for high definition media workflows and can offer extremely high data rates for faster access to media.

Choosing between a NAS or SAN solution will depend on workflow requirements. Sometimes both will be needed. NAS solutions can be used to effectively extend SAN configurations and both continue to benefit directly from the ever-increasing capacity of disk drives and network topologies. Direct attached storage is now used for local caching of files, particularly in cases where extremely high data rates are required and need to be guaranteed.

As a result of this trend, digital workflows are moving away from single system solutions to networked collaborative environments where multiple systems can work together concurrently. Modern digital workflows are therefore highly scalable with master and assistant systems collaborating to complete the task.

Digital convergence

Digital visual effects have become an integral part of modern filmmaking and as the use of digital effects has increased, more and more of the film is being scanned digitally, providing a natural segue into the world of digital intermediates.

Digital intermediates, by providing new creative opportunities, increase the complexities of the film post-production process. Keeping this complexity manageable is key, and requires better integration of the processes within the workflow. This is in turn driving digital color grading to be more easily integrated with the rest of digital filmmaking, particularly visual effects.

Integrating color grading allows filmmakers to more efficiently grade content at the various stages where it is required: at acquisition, when combining various elements into complex effects, or as the final look before printing to film.

The ability to integrate this process allows changes to be recorded as metadata, as opposed to creating rendered files. This enables the grading information to be kept separately and applied only when required. Potentially, it could even be applied as part of the final render of a visual effects or CGI shot.

The future of digital intermediates lies in the ease of collaboration between editing, grading, visual effects and audio. Together these make up the digital film workflow and the drive to greater efficiency and creativity means that modern digital intermediate workflows have to take all these factors into consideration.

A DISCREET PERSPECTIVE
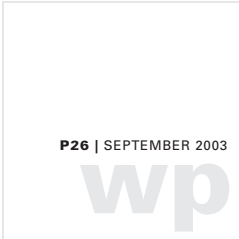
Color grading is the next step in the succesful transition of the film production workflow to a fully digital, non-linear, creative environment. Discreet believes that as with visual effects, software-based solutions will offer superior advantages to the color grading process due to their greater flexibility and scalability, their ability to support any resolution or aspect ratio, and their ability to integrate with the digital post-production workflows that currently exist in high-end post-production and visual effects studios.

More importantly, software solutions offer richer feature sets, can handle more complex creative tasks with greater ease and are easily upgradeable. They consistently provide new and improved tools to meet tomorrow's production challenges and present long-term advantages both in terms of performance and return on investment.

Ultimately the success of any solution is based upon understanding the creative needs of the end-user. The platform it runs on is often irrelevant and will eventually become obsolete. What lives on are the creative tools, constantly evolving and adapting to the needs of the end user and migrating from platform to platform to reach ever new levels of performance and optimization.

Why are creative tools so important? They empower artists providing them with tools that let them, go wherever their imagination takes them. It is this philosophy that has made Discreet a world leader in both digital film technology and post-production systems. Discreet's **inferno**®, **flame**® and **fire**® systems have become digital film tools par excellence. They are able to combine more than 10 years filmmaking heritage with the performance of modern computers to provide, together with **lustre**™, the ultimate creative tools for digital intermediates.

Discreet's digital film systems

Since it was first used on *Super Mario Bros* in 1993, **flame** (and later **inferno**) has been the powerhouse behind some of the most stunning on-screen visual effects. Film credits for **flame** and **inferno** include pioneering visual effects work on hundreds of feature films, including such Oscar®-winning films as *Forrest Gump*, *Men in Black*, *The Matrix*, *Titanic*, *Gladiator*, and *The Lord of the Rings; The Fellowship of the Ring*. Since 1997, 95% of films nominated for the Academy Award® for the Best Visual Effects included visual effects created on a Discreet system, a testament to the outstanding creative capabilities of the Discreet product line.

flame and **inferno** systems offer visual effects supervisors and artists the most sophisticated compositing toolsets in the industry, including advanced color calibration and color management tools for the accurate manipulation of both linear and logarithmic image data, advanced grain sampling and management tools, up to 6K image processing and real-time 2K playback. **inferno** functionality allows artists to truly interact with visual effects supervisors and film directors. It is a powerful design tool where you can test ideas with immediate feedback. As such, **inferno** has become an indispensable part of the creative process at film studios worldwide.

Whether your media is from a film source or digital camera, **fire** and **smoke**® editing and finishing systems offer you the ability to tell a compelling visual story with greater ease and efficiency. Renowned for their sophisticated toolset and pristine image quality, Discreet **fire** and **smoke** systems are used worldwide by the world's most talented editors and artists working on projects ranging from blockbuster feature films to TV drama. **fire** and **smoke** technology allows you to natively edit high-resolution digital-cinema projects without compromising quality. **fire** is the industry's only fully featured NLE offering full 12-bit/component color fidelity, real-time HDTV and 2K playback and support for up to 4K image resolution.

Discreet's **lustre** is an intuitive, high-performance digital grading and color correction system for interactive film look design and creation. The **lustre** system's unique and extremely powerful software design delivers real-time 2K color correction and grading capabilities while providing a rich and sophisticated feature set for working with high-resolution film scans and digital intermediates. Designed to meet the highly specialized needs of colorists and directors of photography, **lustre** provides cinematographers with familiar tools and the unique ability to not only design and create new film looks, but also to fully participate in the color manipulation of their film as it passes through the digital intermediate process.

Éclair Laboratoires
Paris, France

Established in 1907, Éclair Laboratoires is one of Europe's leading film laboratories offering a range of services including negative processing, 35 mm release prints, digital intermediates and digital post-production.

Philippe Reinaudo, director of scanning and recording and Yvan Lucas, Éclair's color timer comment on digital intermediates:

"A challenge with photo-chemical grading a film is having to interpret or guess what the end results will be since there is little opportunity to see what is going on during the process. One of the key issues in the chemical lab at Éclair Laboratoires has been the modification of contrast in film…"

"…Color grading is a very different process than digital grading for video. Video treatment of film images is dangerous since you are altering the nature of the images. With film there is little or no room for error – everything must be perfect since you will see the images on a very large screen…"

"…What is great with **lustre** is the fact that the director of photography, a director and a colorist speak exactly the same language and everything goes very, very fast…"

data Éclair/Discreet workflow

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wp

- w2K Server + 16TB Raid3 Storage
- internal 0.75 TB Raid0 Storage (for HD io)
- receive and store the original 2K, 4K, 6K data files
- generate and store the 1K proxies
- receive the cut, dust and grade list from **lustre** Master
- Render the 2K, 4K, 6K graded files on the render farm
- Manage the render farm

Scanner
Scans 35mm film and generate 2K,4K,6K data files

Film recorder
generates 35mm film from the 2K graded files

lustre render Farm
Renders the 2K graded files

lustre server

discreet
departement cinéma numérique
- Can import original or graded 2K files
- Can directly export files to the server
- Supports HD I/O

inferno / backdraft

lustre Assistant Stations

- (1) internal 0.75 TB Raid0 Storage
- (2) internal 1.5 TB Raid0 Storage
- auto assemble
- Pan and Scan
- Generate the cut list + dust list
- Confidence check, SD I/O
- Dust busting

lustre Master Stations
(with interactive backgd rendering PC)

- internal 1.5 TB Raid) Storage
- auto assemble
- confidence check
- Pan and Scan
- Does the grading with the 1K proxies
- Generates the cut list, dust list, grade list

inferno

flame

flint

smoke

CXFS

inferno

flame

flint

backdraft

Highspeed networking