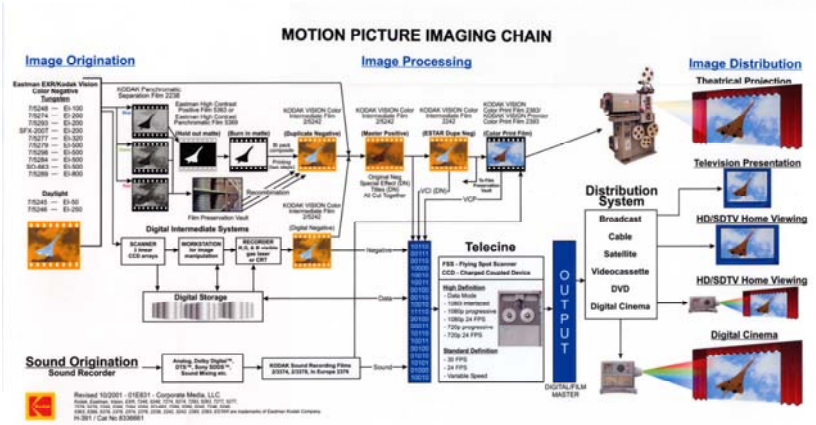
Digital Intermediate

Any discussion concerning Digital Intermediate begins with an understanding of the processes involved in today's filmmaking—film origination, digital image processing, and film distribution. Below is a chart of the "Motion Picture Imaging Chain" that represents an overview of the three parts of the Process—Image Capture, Image Processing, and Image Distribution. Several years ago, Kodak pioneered digital post-production with the advent of KODAK CINEON products. Although these products are no longer available, they were pioneers of this process and formed the infrastructure on which the industry continues to build. Optical effects have almost entirely been replaced by digital workflows, as have special effects.

Motion Picture Imaging Chain



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Digital Intermediate is about using digital imaging science with film-originated images. Every single image of film is digitized and imaging algorithms applied for special effects, color correction, contrast manipulation, restoration, adding computer-generated images, dustbusting, wire and boom removal, speed change effects, certain creative looks, and look changes such as sharpening, degraining, or color timing.

Using the Digital Intermediate process, or DI, provides access to not only digital imaging science, but also to a very highly capable digital infrastructure (computers and workstations, high-quality displays, networks, data storage). It also requires high

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resolution, high throughput equipment for film scanning and recording. Data storage such as storage area networks (SANS), or network-attached storage (NAS), can allow different flexibilities and capabilities for manipulating, storage, and processing of images. There are many hardware and software vendors that have products that take advantage of these systems.

The story of Digital Intermediate begins in the 1990s. Kodak introduced the term with the introduction of their Cineon system, which included the Genesis digital film scanner (capable of scanning up to 4K resolution), the Lightning laser film recorder (also 4K recording), and Cineon software (which was supported by the Kodak digital imaging system with an object-oriented workflow or flow graph that served as a model for the industry). Originally, "Digital Intermediate" was a delivery element. It included scanning at the highest resolutions available, creation of digital data files, and output to film for theatrical distribution—Film In, Digital Manipulation, Film Out.

"Pleasantville" was the first movie to utilize a significant amount of negative digitalization, but "Oh Brother, Where Art Thou?" was the first completely digitized—Digital Intermediate—feature film.

From the beginning, DI has faced the major obstacles of productivity and cost. Initially, DI was a very expensive and slow post-production process. Recording images and data file transfers in a facility remain the chokepoints in the DI process. However, the continuous development of key technologies such as real-time high-resolution data scanners, higher speed recorders, faster computers and workstations, very high capacity, and affordable storage are making DI more economically viable today. More than 400 movies have gone through this process over the past few years and today, DI is a reality for more and more customers. It is becoming the "norm" just as nonlinear editing and digital sound have.

Digital Intermediate means post-producing a movie in a digital format. The digital formats can vary from post-production facility to facility. Once the Digital Master is ready, an intermediate is recorded back to film, and the final prints produced in the usual way. However, this same "digital master" can also be converted to DVD or TV broadcast formats, or as a movie that can be projected in a Digital Cinema theater. Each viewing medium has its own color gamut and must be graded on the intended display device for preserving the creative content of the director and cinematographers.

DI today relates to any long-form project that is entirely post-produced digitally. The Image source input can be from color negative film and/or digital cinematography cameras (RGB data, not video). The final result is a Digital Source Master from which all film and video deliverables can be produced. For film prints, a Digital Negative is produced for making either an IP/DN or Direct prints for theatrical release.

For Filmmakers, DI offers the following benefits:

- Flexibility and immediacy
- Multiple and different versions of content, trailers, and teasers

- Localized version of language or subtitles
- Full color correction (i.e., primary and secondary)
- Full editorial capabilities
- Large screen displays for evaluating interactive digital image process
- Less costly last-minute changes
- High image quality of optical effects (fades/dissolves, composites, etc.)
- Image repair
- Text capabilities (titles, subtitles, and credits)
- As DI processes continue to improve, it will result in image quality improvements in the 137,000 film cinemas around the world

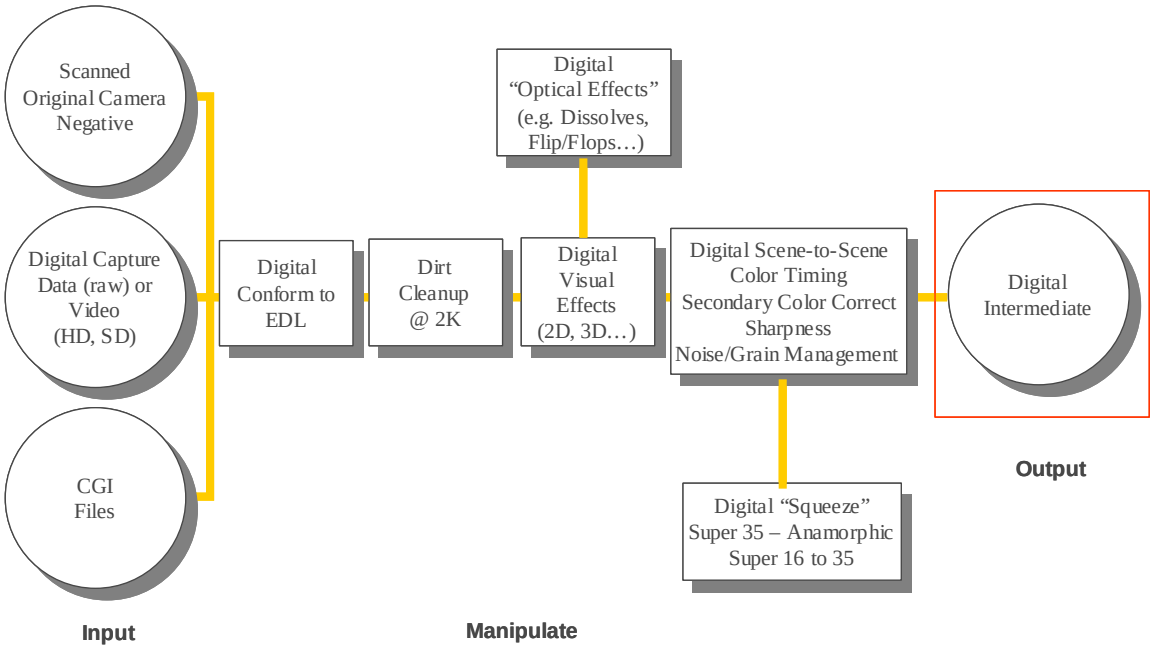
However, there are many disadvantages as well:

- Too many creative opportunities and decision makers, which can lead to a time-consuming process ("fix-it-in-post syndrome")
- Expensive hardware, software, and networks are required
- Equipment obsolescence
- No long-term digital archiving medium except on film
- High level of expertise and complementary skills required
- Low-speed image processing (rendering) and film recording

And what DI means depends on whom you ask and where you are in the workflow. As processes unfold and as digital tools are applied, so do the terms customers use.

In today's digital environment, there are a number of options that can be used throughout the entire DI process. However, with each option there is the potential that the integrity of the film images will be compromised. How Images are input is the first of many choices customers need to make as their project enters the DI workflow.

What do we call the output of a DI Workflow?



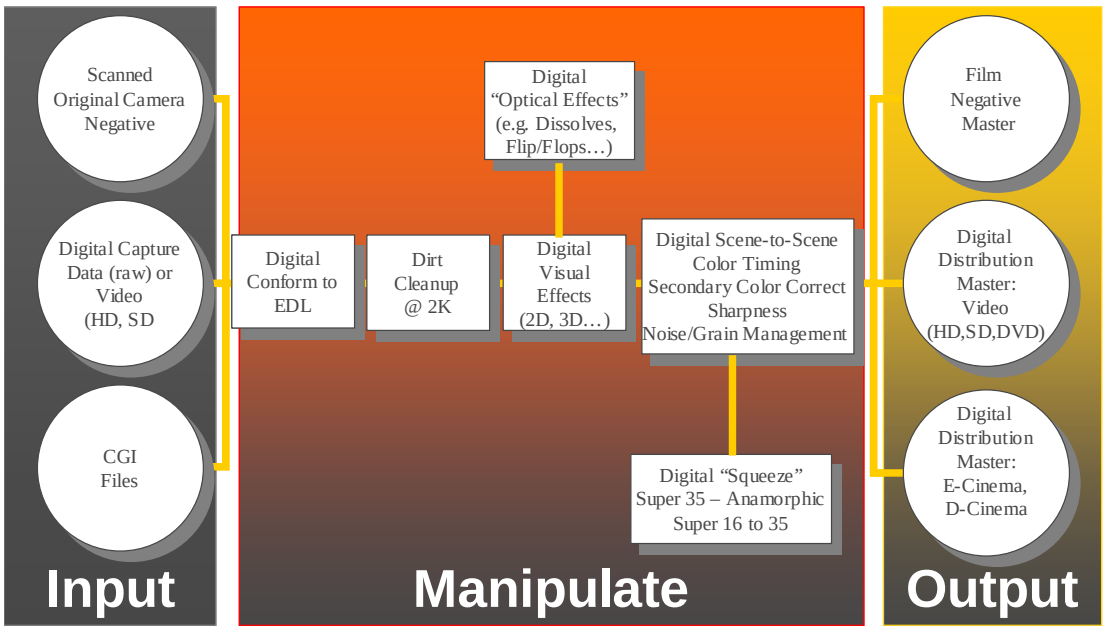
Besides film, there are many types of images captured electronically. There are also computer-generated images (CGI), which may become part of the workflow. Both of these are generally characterized as linear data. How this data is stored and later, manipulated, are additional, important choices that customers make. Each digitally captured or (CGI) is used in a different workflow than film-generated and scanned images.

In the middle part of the workflow is the greatest potential for data to be compromised. There are many different types of digital tools at work here—hardware and software: displays, processors, data networks, etc. As data moves from one step to the next, decisions concerning data spaces and color management are key decision points for preventing the compromise of quality and integrity of the images.

A Closer Look at the DI Process

The typical flow can be analyzed in terms of the following three major steps:

- Input
- Manipulate
- Output



The **Input** is a data file. "Images" are produced from high-resolution (>2K) scanned film, lower resolution DVCAM, HDCAM, HD, standard def video, computer-generated RGB images, or from a variety of Digital Cameras with varying resolution algorithms.

Manipulate consists of a whole range of transforms to which the images will be subjected: color correction, look management, special effects, editing, conforming, formatting, and fades/dissolves, etc.

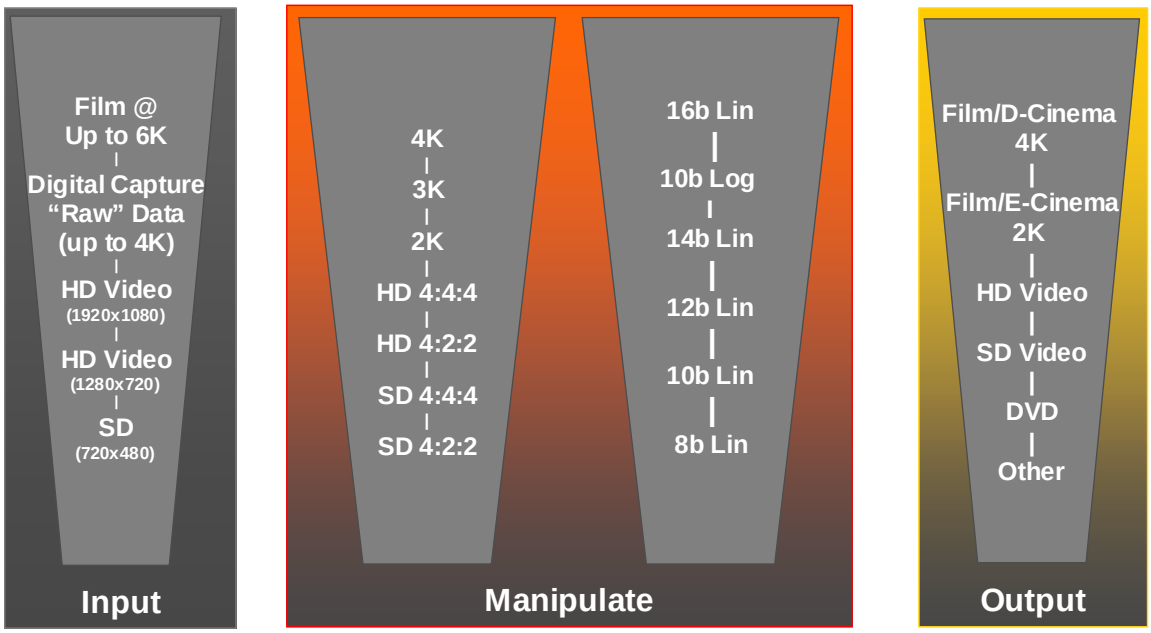
And **Output** is the form in which the movie will be distributed. That includes film, digital projection, HD, DVD, and standard definition video.

Every image at every step in the DI Workflow is characterized by two attributes: resolution and color space.

Resolution is measured spatially, in numbers of lines in both the X and Y axes. Color Space is measured in bit depth, in how many units of color and luminance present in a digital image. Both of these attributes affect the integrity and quality of the Digital Intermediate Master, or Final Output.

Below is a useful diagram for examining the choices available at each step of the DI Workflow:

“DI”, A Closer Look



Input files can originate from the lowest resolution and color space of digital video to HD video and up to the maximum resolution and color bit depth of scanned film. Likewise, Data manipulation can occur at various resolutions and color spaces—from Standard Definition video up to 12-bit logarithmic data: the highest resolution and bit depth of scanned film. And finally, Output follows the same pattern, from the lowest resolution and color space of video up to that of film recorded at 4K.

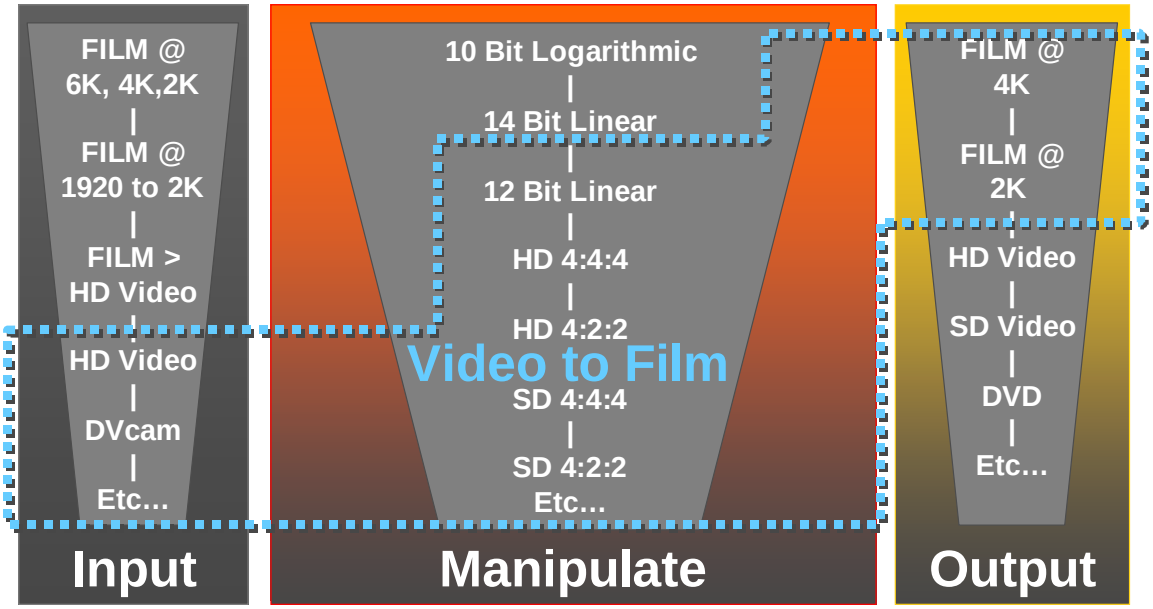
The integrity of the Input files and how they are manipulated will affect the resulting quality of the Output.

Obviously, footage recorded on a DV camera can be recorded to film at 4K, and film scanned at 6K can be output to a DVD; however, choices must be made at each step in the DI Workflow that affect the resulting integrity of the Digital Intermediate Master (output). However, when the input is of higher resolution (e.g., scanned film), going downward in resolution and color space is always feasible. The reverse—going upward in resolution and color space from video to film—is not as high quality in the end result. This is referred to as up-sampling and many algorithms are used to do this.

“Video to film” spans from lower end image capture to HD 8:8:8. Keep in mind that an 8:8:8 format results from the Y, Cr, and Cb samplings at every pixel site, and intermediate values are computed by interpolation to add precision in image transforms as rotation.

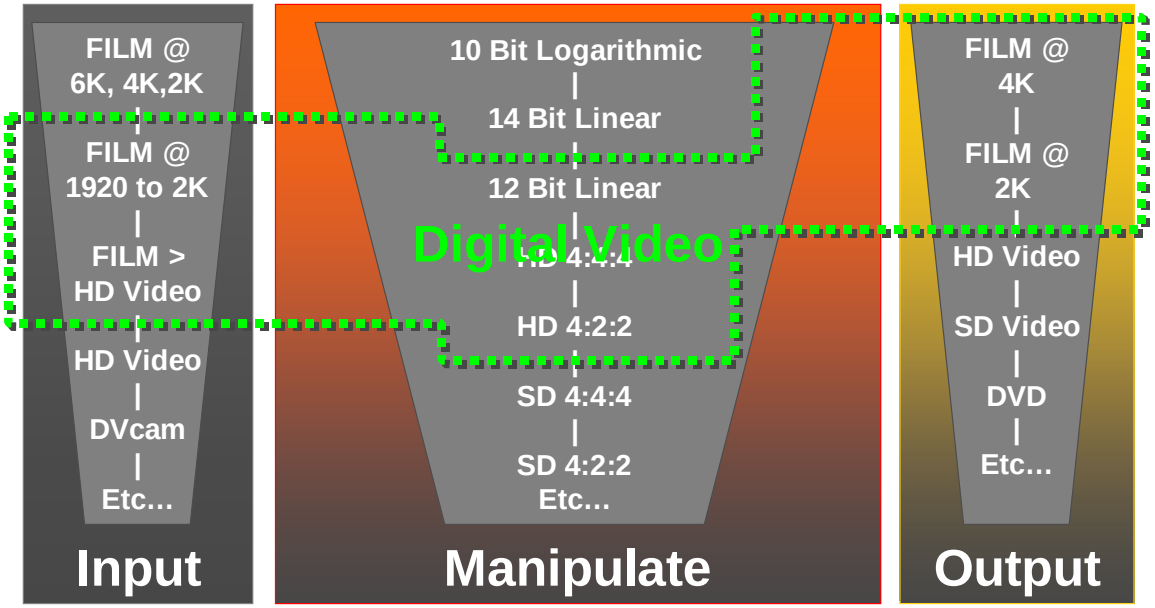
In technical terminology, this is not a Digital Intermediate. The input and the image manipulation steps are of lower quality and may introduce digital artifacts in the output image.

Video to Film…



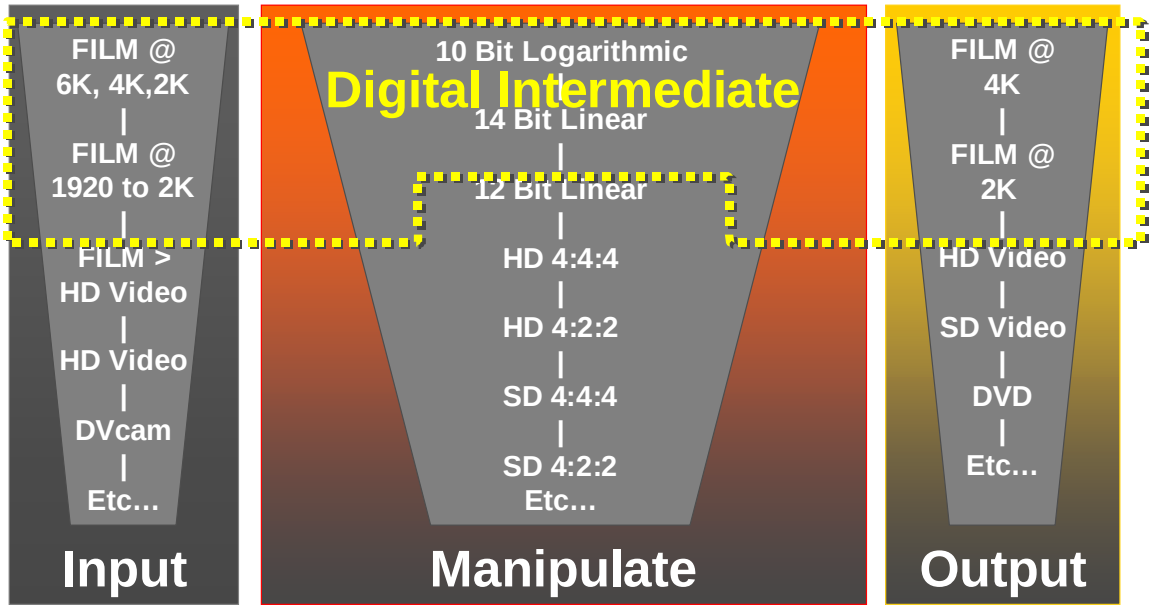
Although Digital Video post-production operations are up the quality chain, Digital Video is not Digital Intermediate either.

Digital Video to Film…



Digital Intermediate applies to film scanned at 2K resolution minimum and digitally processed with the highest resolution bit depth and format at all times.

Film to Film… High End Digital Intermediate



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The three key aspects of Image Quality that are part of the DI process are:

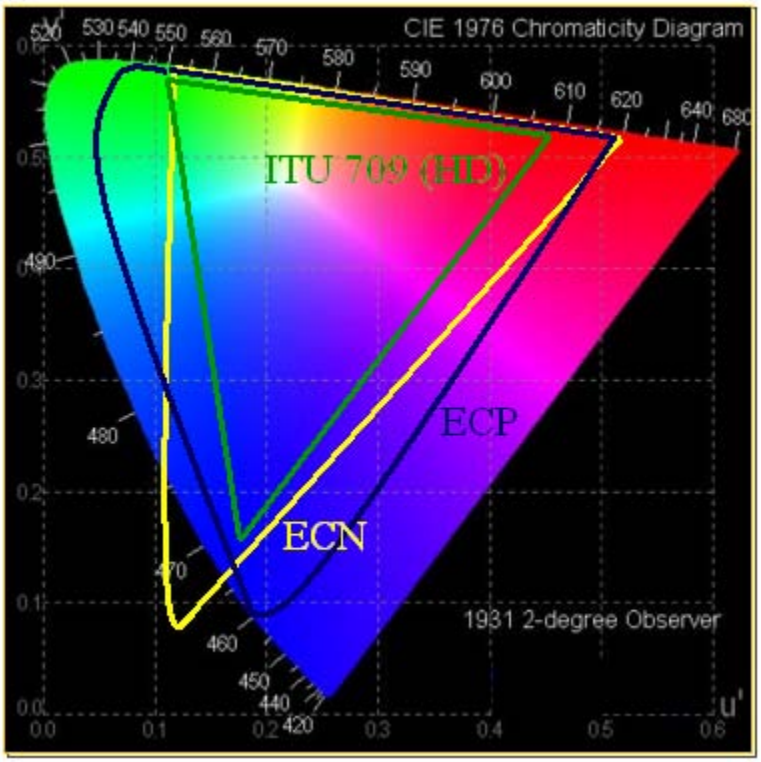
- Image space
- Resolution and sharpness
- Color management and calibration

Image Space

The human perception of color, details, and lightness is based on the utilization of cones and rods, each having different spectral and absolute sensitivity. The human eye can be considered as a digital camera with a variable focus reflex lens, gray scale sensors (rods), individual red, green, and blue sensors (cones) with large size variations, arranged in a high-frequency pattern in the retina, and a very sophisticated image processing system in the brain that is totally image adaptive. For example, we see a difference in light from 1 to 2 the same way as 100 to 200. That is considered a logarithmic scale and is the same way that film sees light.

The human visual system or HVS can be described as a Red, Green, Blue, and Luminance system working in a log space. This is a chromaticity diagram that depicts the different color gamuts of different systems.

Color Gamut



Obviously, many different technologies can represent an image: negative film onto print film, CCDs, inkjet printers, scanners, recorders, CRT displays, LCD displays, and Micro-mirrors in some digital cinema projectors. All of these technologies can provide a representation of an image. However, each of them will use a different image space. Some will be linear, some will be log based. Some will be RGB, some will be YUV, some will be color subsampled, and some will not. They will vary in terms of bit depth, spatial resolution, color coding, etc.

The image space will define how a given technology represents an image. In the diagram above the "Color Space" for Color Negative Film (ECN), Print Film (ECP), and HD Video have been overlaid to illustrate the limitations of each.

Resolution and Sharpness

The chart below reports the pixel resolution obtained by scanning 35 mm format film using sensors capable of capturing from 2K to 8K samples across each frame line. Higher resolution scanning preserves more of the image detail captured in the film.

2K	2048 x 1556	40 cycles/mm
3K	3072 x 2334	60 cycles/mm
4K	4096 x 3112	80 cycles/mm
8K	8192 x 6224	160 cycles/mm

Keeping the detail information captured by film throughout the entire DI process ensures that what the cinematographer has seen and wanted will be actually reproduced. Scanner technology is improving, and 4K is being more widely used today.

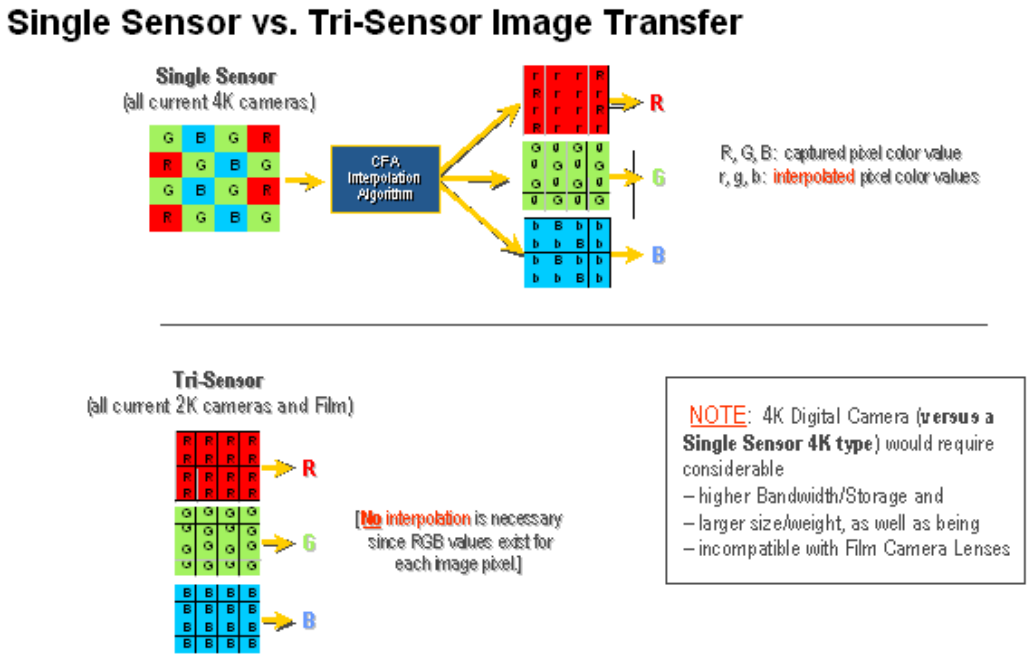
How Many Bits?

Resolution is only one part of the story. Resolution applies to the spatial sampling of the image. The other part of the digitization process is quantization. The human eye is more sensitive to equal brightness changes in the shadows than in the highlights. By using logarithmic sampling such as film density, more intensity levels can be allocated to represent shadow detail. In order to approach our Human Visual System, a 10-bit log sampling is often used, as it allows a better representation of the shadow details.

However, some systems work in a linear space where10-bit log is the equivalent of 12- to 13-bit linear. As computer power increases, and as the demand for consistency along the imaging chain is of paramount importance, more bits will be used in the future. Eventually, higher bit depth linear may be the choice (32 bit is beyond eye capability).

8 bit	2^8 gradations	256 intensity levels
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	2^{32} gradations or floating point	4.3 billion intensity levels

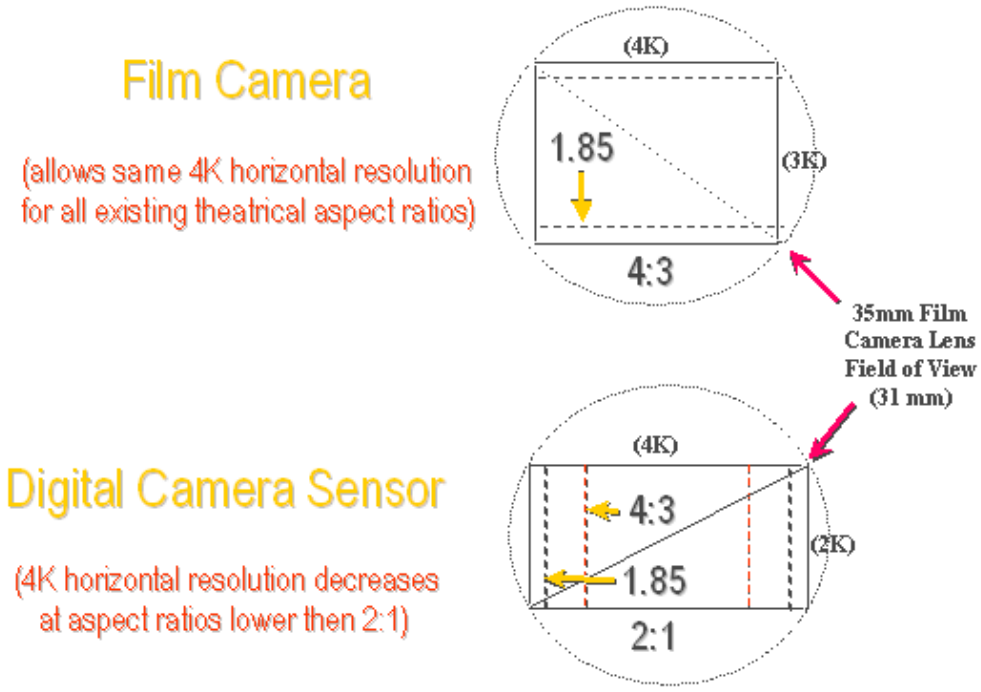
When images are captured with a digital camera having a single sensor and a color filter array (CFA), each pixel captures image information in only one color (red, green, or blue). To obtain a fully populated color plane (R,G,B at each pixel site), like film does, it is necessary to mathematically generate the two missing colors at each pixel site. This mathematical process can introduce chromatic artifacts that significantly reduce image quality, particularly when subjects with repeating patterns and motion are captured. There are digital cameras available that use three separate sensor arrays to capture R,G,B information at each point in the image plane, but they have complicated relay optics, require higher bandwidth storage, and are incompatible with 35 mm Cine lenses.



[Therefore, **Higher Color Resolution than Single Sensor** type]

There are also Resolution compromises when it comes to the Aspect ratio of the Image.

Resolution Aspect Ratio Relation



During image processing of the data, there are many possible areas where the image integrity can be compromised. Digital Intermediate Workflow is much more complex than a Video Post-production.

Digital Video Post-Production vs. Digital Intermediate

	Digital Video Post-Production (DV)	Digital Intermediate (DI)
Data	In a stream like water in a pipe	In computer files – generally CINEON or DPX
Precision	Low precision – Generally some form of 8 to 12 bit linear with gamma	High precision - 10 bit log going to 32 bit FP
Speed	Real time	Seconds per frame
Resolution	Up to 1920 pixels/line	2048 to 6224 pixels/line
Color sub-sampled	Almost always	Never
Compression	Always	Never
Dynamic Range	Supports 10 stops	Supports 20 stops

Color Management and Calibration

Consistent image color is needed throughout all operations of the DI workflow. Color Management is the use of appropriate hardware, software, and methods or procedures to control and adjust color in an imaging system ("WYSIWYG" concept). The final output must match the image seen in the Digital Intermediate suite. This requires that each part of the workflow be calibrated independently. There needs to be assurance that errors in one part of the workflow are not compensated for by more errors later in the workflow. Images can be exchanged between post-production houses at any time, and this requires some sort of common format. For now, the Kodak Cineon file format, ratified by SMPTE as the DPX file, is the cornerstone of the Digital Intermediate Workflow.

But even the best color management system will not provide good results if the various elements of the workflow are not perfectly tuned or calibrated to a standard. This applies not only to the monitors and digital projectors that are used in the workflow but to scanners and recorders as well. Every single element of the workflow has to be properly calibrated. A post-production facility can be internally calibrated, but may not be able to give a data tape to another facility and them being able to use it appropriately to achieve the highest quality product. Lab processing is also a consideration when using film systems and need to be accounted for in an ideal calibrated system.

The same sequence of images will eventually go through various digital steps, such as contrast adjustment, exposure correction, and special effects. Each step may involve a different image space. In order to avoid any degradation of these images, a device-

independent image space is required. For this reason, the DPX file format is the current format of choice for the Digital Intermediate Workflow.

After the program has been managed in the workflow to the point of distribution, it may be sent to a CRT, LCD, or laser film recorder to produce the Digital Negative, Digital Interpositives, or even a Digital Print. The common practice today is to output images in 2K resolution at relatively slow frame rates. These Digital Negatives are used to produce either Direct Prints for Release or Interpositive/Duplicate Negatives for Release printing. As recorder technologies improve, higher resolutions and faster recording rates will become possible. There are some higher resolution scanners and recorders available on the market, but the data pipeline then becomes cumbersome and expensive. The very high resolutions are used on large format and special projects.

For Digital Cinema Distribution, a Digital Cinema Distribution Master (DCDM) is produced. Currently this Master is formatted according to the Digital Cinema Initiative specification and SMPTE DC-28 standards that will be used for playback and display. Piracy and security are also important parts of the digital cinema standards.

For the lower quality outputs, digital masters are made for producing DVDs, HDTV, and SDTV Broadcast versions, etc.

If the integrity of the Image has been maintained throughout the Digital Intermediate Workflow, the customer can be assured that every version of the project—35 mm film print to DVD—will have the best image quality possible.