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Capturing Information on Film

Source

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Key concepts

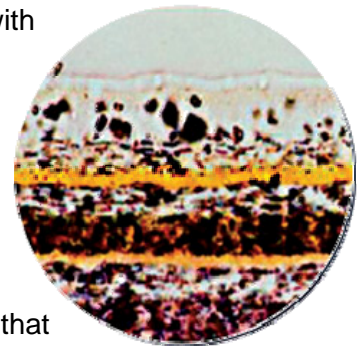
- A single frame of 35 mm color negative film scanned at 4K x 3K contains approximately 50 MB of data.
- Typical CCD or CMOS electronic cameras capture 8 to 10 MB of data.
- Film contains a random pattern of billions of silver halide crystals.
- An electronic photo-sensor uses a fixed array of sensors.
- Electronic capture requires trade-offs between high-resolution capture and dynamic range.
- Film can be scanned and converted to any video format without introducing image artifacts.
- Film is the ultimate storage medium for moving images.

Introduction

How much information can be captured on one frame of 35mm color negative film? How does that compare with the best digital image capture systems? We put those and other related questions to Nestor Rodriguez, senior principal scientist for the Kodak Entertainment Imaging division.

Question: How much image information can be captured and stored on a single frame of 35mm color negative film and how does that compare to today's best digital cameras?

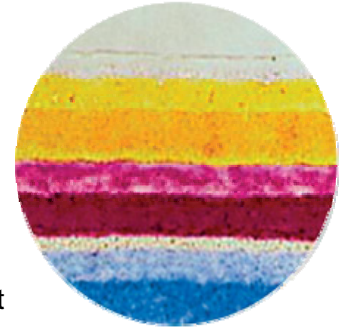
Answer: A single frame of color film scanned at 4K by 3K resolution with 10-bit depth contains about 50 megabytes of data. However, there is actually a lot more information than that on each frame of 35mm film. We have conducted tests where we have scanned film at 6K by 4K resolution at 10-bit depth, resulting in about 100 megabytes of data, or twice as much image information. In comparison, a typical CCD or CMOS RGB three-sensor 1920 by 1080 electronic camera with 10-bit depth records 8 megabytes per frame, assuming that there is no sub-sampling or data compression. A single CFA sensor 4096 by 2048 camera records about 10 megabytes of data. So the simple answer is that today's best film technology enables you to record 5 to 10 times more picture information on a single frame than the best contemporary digital cameras.



Color negative layers before development

Question: What are the main differences between the way images are recorded on film and digital, aside from resolution?

Answer: Film is analog, like the human eye. It sees and records continuous tonal gradations between black and white. There are many complexities and nuances in the way film captures images. For example, film requires a certain threshold in exposure to light before it begins forming latent images. This gives cinematographers extraordinary flexibility for manipulating light in ways that create subtleties in textures, contrast and colors that are part of their visual vocabulary. Every frame of film consists of layers of emulsions that respond to different areas of the color spectrum to produce a result that



Emulsion layers after development

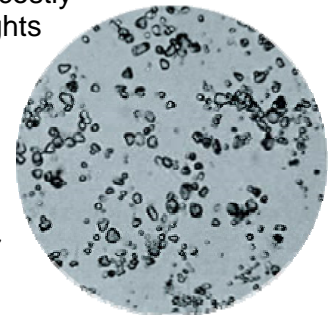
represents the red, green and blue light for every single point captured in the original scene. Each layer in every frame contains a random pattern of billions of T-Grain silver halide crystals, color couplers and other chemicals embedded in a gelatin emulsion. Light causes a chemical reaction in the crystals to create latent images consisting of small clusters of silver specks. The latent images are amplified billions of times when the negative is processed.

The CCD sensor in electronic cameras consists of a rigid pattern of pixels. A sensor pixel requires a minimum threshold (exposure) of photons before it generates an analog charge that is translated into an analog voltage. The voltage is amplified and passed along to one or more A/D (analog to digital) converters that put it into numerical values. Instead of latent images, there is a numeric representation of picture data captured by a rigid array of pixels.

Question: Are there any other significant differences?

Answer: There are significant differences in dynamic range. The more costly electronic cameras can record details in shadow areas, however highlights lose their texture and color by becoming blown out.

An electronic camera designed for a particular image frame size format (e.g. 35mm) has to choose (trade-off) between resolution, and dynamic range (including sensitivity). When squeezing more pixels into the CCD sensor to obtain higher image resolution creates smaller pixels that capture less photons and hold less charge, resulting in lower ISO speed and exposure range.



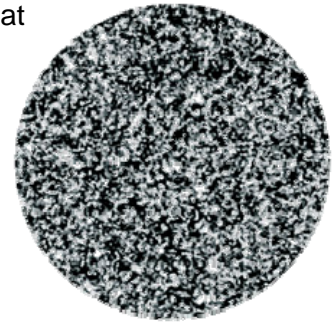
Silver halide before development

Question: How do these differences translate into practical advantages or disadvantages for cinematographers and their collaborators on actual projects?

Answer: One example is that in challenging environments, where filmmakers have less control, film can handle overexposure in a natural-looking way due to its slow roll-off (nonlinear) response to high exposure levels. Digital cameras do not handle overexposure nearly as well because they clip at extreme brightness. In addition, the small pixels required to obtain high-resolution images saturate with light much faster than larger ones. This causes the image to clip or “blow out.” Once an electronic image has clipped highlights, no amount of post work or money can bring those details back.

Question: Are there other differences in terms of format flexibility?

Answer: Film can be scanned and processed to meet almost any format requirements. Whether the need is for standard definition, high definition, or something else in the future, the same film can be used to conform to different formats. As scanners and signal processing technologies continue to improve, the same film can be rescanned to take advantage of advances in postproduction and display technologies. In other words, today's best films will look even better tomorrow. If and when electronic display technology improves, today's electronic productions are likely to be obsolete.



Silver halide after development

Question: How about the Super 16 film format? How does that play on HDTV?

Answer: With the continuing convergence of advances being made in film and digital intermediate technologies, more low-budget films and television are being produced in Super 16 format. Some television networks had some concerns because data files used for HD broadcast are compressed and they saw some evidence of grain with programs originated in Super 16 format. That shouldn't be an issue with today's Kodak VISION2 emulsions. Countless motion pictures, episodic series, documentaries and even commercials that were produced in Super 16 format have aired in HD format around the world.

Question: What about archivability?

Answer: Turn on your own television set and scan through the available channels. Chances are you will see memorable motion pictures and television programs that were produced 40 years ago and more. A film record is a "human readable" optical image reproduction of the original scene, and as such, it does not rely on a specific image recording encoding algorithm and hardware to "read" back those images. If you are venturing on a project that you believe deserves to be seen by future generations, we recommend that you record it on film and then archive the negative properly.

Question: What is the status of digital archiving formats? Does film still offer the best archival alternative?

Answer: Film is the ultimate storage medium for moving images. Properly archived films will last for hundreds of years. Digital files are much more volatile. I believe that all of the major Hollywood studios are now making black-and-white protection masters of their films for posterity, and I imagine they will ultimately decide to convert titles originated in digital format to film for archiving. One problem is, what do you do with the outtakes you might want in the future?

Film is currently the only true archival medium that will ensure future dividends as the HD household population expands and evolves. Conversely, the best digital storage media have a short life span even under optimum conditions, and digital formats are constantly changing.

Film is by far the most reliable way to archive images. Black-and-white separations will last for up to 500 years, and color negative and intermediate stocks will last for hundreds of years. Digital video is an improvement over analog video signals, but the storage medium is still either a magnetic tape or disk, which is comparatively volatile. According to the Library of Congress, the best magnetic storage media—the media usually used for digital video and HD images—can be depended on for a decade. Once a digital signal is gone, it's gone forever. More than 75 video formats have been introduced since 1956, and even if the media survived, in many or most cases, there is no equipment for playback.

Terminology and definitions

Bit depth—A measure of the amount of information each pixel contains. A one-bit color pixel would be $2^1 = 2$ colors—black and white. A 10-bit number would represent 2^{10} or 1024 possible options. A 24-bit system sees 16.7 million colors.

CCD—Charged Couple Device. A device that converts light into an electrical charge that is then converted to voltage to create a digital image. The number of light-sampling points a CCD makes determines the pixel resolution it is able to create.

CMOS—Complementary Metal Oxide Semiconductor. An imaging sensor that is used in some digital capture devices.

CFA—Color Filtering Array. Tri-color (red, green, blue) filters that allow a photo-sensor to divide light into red, green, and blue components for color output.