Basics

by Helmut Kraus

Normal 8, Super 8, 16mm, 35mm, CinemaScope, 70mm, Panavision—these are just some of the huge range of shooting formats available in the analog movie world. Unfortunately, things are just as confusing in the new, digital video world. The resolution and frame rates of digital video formats are more related to those of conventional video and TV formats than to those of their movie counterparts. The HD and HDTV labels also come from the world of TV, but don't really make it clear what level of image quality a device will produce.

The technical quality of digital video is influenced by a large number of factors. In addition to the resolution (i.e., number of pixels) of each individual frame and the frame rate (the number of individual frames shot per second), memory format and data compression also play a significant role in determining the quality of your results. Let's take a look at the most important factors individually.

Video Formats and Resolution

Just like analog film, digital video is comprised of a sequence of individual images or "frames". A digital camera captures these frames with an electronic image sensor and saves them in digital form. Just as different analog film formats (8mm, 16mm, 35mm etc.) produce differing image quality and maximum projection sizes, different digital video formats also produce different results.

It is not long since the first consumer-level digital cameras with built-in video modes appeared. This functionality was initially limited to shooting two-minute mini-movies with an image size of 320 × 240 pixels or less. Movie modes were at first only offered in compact cameras and didn't become available in professional-level devices for quite a while.

As technology improved, in-camera data processing speeds increased, and faster data transfer rates coupled with larger memory cards made it possible to record longer movies at higher resolutions. The latest digital cameras offer comprehensive video functionality at very high resolutions.

Today's digital video resolution far exceeds that of traditional NTSC TV pictures, which have a resolution equivalent to approximately 0.34 megapixels. High-resolution video is generally described as being "High Definition" (HD). The term HD is not precisely defined, and is used to describe resolutions of 1280 × 720 as well as 1920 × 1080 pixels. The latter format is often described as "Full HD", and is already used for many contemporary film productions. In future, all TV pictures will be broadcast in HD format. Most new TVs are capable of reproducing HD pictures,

Format	Image Width (in pixels)	Image Height (in pixels)	Aspect Ratio	Total # of Pixels	• Comments
PAL	768	576	4:3	442,368*	European TV format, half-frame transmission with 288 vertical lines*
NTSC	720	480	3:2	345,600*	American TV format, half-frame transmission with 288 vertical lines*
QVGA	320	240	4:3	76,800	Mini-movie format built into early compact digital cameras
SQ / 360p	480	360	4:3	172,800	
HQ / SD / 480p	640	480	4:3	307,200	SD = Standard Definition, a common image size in many camcorders
	852	480	16:9	408,960	
HD / 720p**	1280	720	16:9	921,600	AVCHD Lite format
HD / 1080i*	1920	1080	16:9	2,073,600*	• Half-frame display with 540 lines*
Full HD / 1080p**	1920	1080	16:9	2,073,600	
2K	2048	1080	>17:9	2,211,840	Professional film formats
	2048	1536	4:3	3,145,728	
4K	4096	2160	>17:9	8,847,360	

•* see "Interlacing" below

•** p = Progressive Scan, see the following sections

Common digital film formats—names and sizes and the HD-capable digital cameras available on today's market make it easy for photo enthusiasts and professional photographers alike to shoot HD video.

The table lists the most important digital video formats and the illustrations on the next page show the physical differences between them. The detail images on pages 8 and 9 make the differences in image quality produced by different image sizes very clear.

The largest formats currently available in digital compact and DSLR cameras are equivalent to the 720p and 1080p standards.

Frame Rates and Refresh Rates

Another important video parameter is the **frame rate**, which defines the number of individual frames recorded per second (fps). The higher the frame rate, the smoother the resulting action will appear. The human eye perceives sequences of images projected at speeds of 16 fps and faster as a single movement. However, such movement only appears genuinely smooth and jerk-free at frame rates of 20 fps and more.

Cinema Projection

Movies are generally shot at 24 fps. This is a relatively low frame rate and can cause slower movements to appear jerky. Camera operators and directors circumvent this problem by avoiding the use of pans when shooting slow action.

Movie projectors use a simple trick to help film action appear smooth. The sequence of frames in a strip of film is transported through the projector at exactly the same rate it was shot (i.e., 24 fps), and a rotating shutter is used to cover the projector's light beam each time the film moves forward to the next frame, thus preventing the viewer from seeing the interruptions caused by the film's progress.

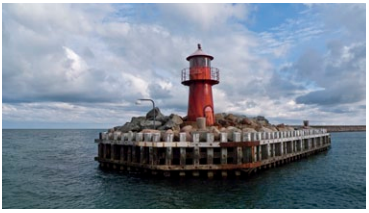
However, the human eye is especially susceptible to the differences between light and dark, and the dark phases between frames cause a strong flicker effect. In order to overcome this effect, the shutter is rotated at sufficient speed to break the light beam two (or even three) times between each frame. This means that each frame is, in fact, projected two (or three) times, resulting in a **refresh rate** of 48 or 72 Hertz (or Hz). The human eye can no longer perceive flicker at such high refresh rates.

Interlaced TV and Video Applications

A completely different technique is used to show film on a TV screen. A conventional CRT display uses a beam of electrons to project each

Full HD: 1920 × 1080 pixels

HD: 1280 × 720 pixels



HQ/SD (16:9): 852 × 480 pixels

HQ/SD (4:3): 640 × 480 pixels

PAL: 768 × 576 pixels

SQ: 480 × 360 pixels

NTSC: 720 × 480 pixels

QVGA: 320 × 240 pixels

individual film frame onto the screen line by line. This process is time-consuming, and made it impossible for early TVs to refresh each frame the way movie projectors do, causing TV films to flicker noticeably.

The scanning time for each frame had to be reduced to make higher refresh rates possible, and the solution is the so-called **interlacing** technique. This technique projects every second line of each frame onto the TV screen, using the odd-numbered lines for the first projection and the even-numbered lines for the second. This way, a refresh rate of 60 Hz (equivalent to the frequency of household alternating current) produces 60 half-frames per second instead of 30 full frames. Our eyes convert the jumps from line to line effortlessly into a whole image, resulting in a flicker-free viewing experience. We do not see the dark lines where no image information is projected because conventional CRT screens phosphoresce for a short period after each image line has been projected. The construction of the human retina, with more rods than cones at its edges, makes us more susceptible to flicker effects at the edges of our field of view. In spite of recent technological advances, TV pictures are still broadcast as half-frames.

Interlacing is also used to shoot video, resulting in each video frame having half the height of the full image. This is why video pictures (especially where horizontal motion is involved) often appear to be covered in horizontal stripes. The individual frames covering the movement were actually shot at different points in time and are thus displayed with a slight time lag.

Full-frame or Progressive Scan Projection

Modern TFT/LCD and plasma screens address each individual pixel directly and no longer need to use interlacing techniques to produce flicker-free moving images. The entire picture is always immediately visible, just like the image created by a movie projector. This projection process is called **full-frame** or **progressive scan**. Here too, refresh rates are increased by projecting each frame twice, or by projecting interim

Digital video formats

Size comparison of the most common formats. Images as the top and on the left show old and new TV formats, while the images on the right show video camera formats.

Full HD: 1920 × 1080 pixels

HD: 1280 × 720 pixels

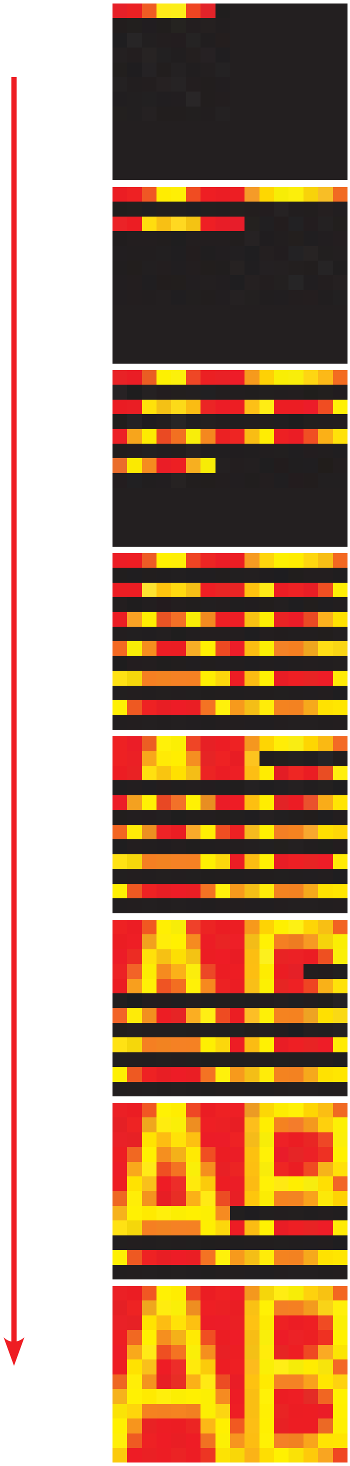

HQ/SD (16:9): 852 × 480 pixels


PAL: 768 × 576 pixels


QVGA: 320 × 240 pixels

Size comparison of digital video formats

These pages show examples of single frames for five selected video formats. Each example also includes two details enlarged to the same magnification. Image detail is clearly inferior for the smaller formats.



images computed using an interpolation algorithm. This way, modern TVs can achieve refresh rates of up to 200 Hz. Virtually all modern computers also use full-frame techniques to drive their displays.

General Terminology

The deeper your interest in video resolution and digital image quality, the more often you will come across the special terminology used to describe the techniques involved. Here are two examples of video nomenclature, including short explanations of what the individual terms mean:

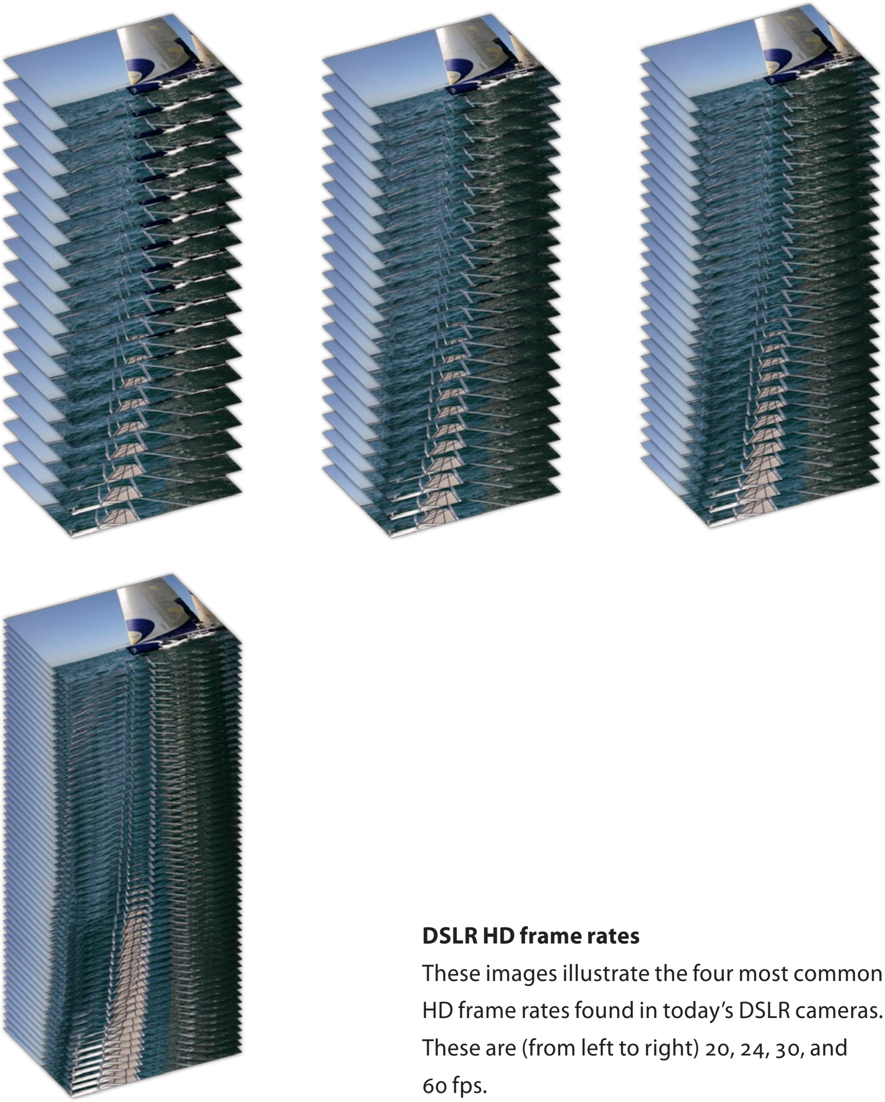
Example #1: **720p50**
"720" describes the frame height in pixels. The entire frame has a total size (in 16:9 format) of 1280 × 720 pixels. "p" stands for "progressive scan" and "50" denotes the frame rate (here in full frames/second).

Diagram of an image being written in interlaced mode
The cathode ray starts in the top left corner of the screen and first writes the pixels for the odd-numbered lines. Once the ray reaches the bottom right corner of the screen, it writes the even-numbered lines, once again starting at top left. These two "half-frames" are usually written one after the other with a slight time lag.

Stripy interlaced image
The time lag between the writing of odd- and even-numbered lines in an interlaced image can cause stripes to appear in footage of fast-moving subjects. The individual frames in a sequence usually follow each other too quickly for this effect to be visible; the human eye only perceives the stripes when the action is paused.

Example #2: **1080i60**
"1080" describes the frame height in pixels. The entire frame has a total size of 1920 × 1080 pixels. "i" stands for "interlaced", and "60" defines the frame rate (in this case, 60 half-frames/second).

DSLR Frame Rates
Clips shot using digital compact or DSLR cameras are comprised of



DSLR HD frame rates
These images illustrate the four most common HD frame rates found in today's DSLR cameras. These are (from left to right) 20, 24, 30, and 60 fps.

full-frame images, and are thus more similar to conventional movies than to clips shot using video cameras. The frame rates available in most digital still cameras currently lie between 20 and 30 fps, although some DSLRs are capable of shooting Full HD video at rates of up to 60 fps, making it possible to shoot slow-motion sequences too. The difference between clips shot at 24 and 30 fps is visible to the human eye, and fast movements shot at 30 fps appear much smoother. Twenty fps is simply too slow for shooting fast-moving subjects satisfactorily.

Digital frame rates are limited by technical factors, and depend mainly on the number of output channels built into the image sensor. Sensors with multiple output channels are more expensive, but can record image data more quickly by using all the available channels simultaneously. Cheaper cameras therefore usually have slower maximum frame rates. At least four output channels are necessary in order to shoot Full HD at 60 fps—a feature currently only offered in ultra-high-end DSLRs.

Some cameras limit the frame rate according to the size of the image being shot (e.g., a maximum frame rate of 20 fps for 1920 × 1080-pixel images, or 30 fps for video shot at 1280 × 720 pixels). A smaller image size is usually preferable to a lower frame rate for most subjects. A shake-free HD sequence appears more natural (and professional) than a shaky Full HD sequence.

Playback Frame Rates

Video and TV playback frame rates depend on the playback technique being used (PAL or NTSC), whereas digital video playback frame rates can be adjusted more or less at will, depending on the software you are using (QuickTime, iTunes, VLC, etc.). It is important to select the frame rate most appropriate to your chosen playback device when processing video material. In order to achieve the best possible reproduction, you may have to change the frame rate, which will usually involve using editing software to resample the entire sequence.

Digital playback is not subject to these restrictions. If your DSLR can shoot at 30 fps, you can play your material back at 30 fps without first having to convert it to a slower rate, as is usual for video productions. Most media players automatically detect the frame rate and play recorded material back at the appropriate speed.

Data Formats and Data Compression

We have already addressed the differences between the formats and frame rates used for shooting digital video, but the data formats used for saving digital material are even more varied. Saving digital video material always involves a compromise between saving the most possible audiovisual detail while reducing the size of the resulting file to a manageable size. If video were to be saved without compression, you would very quickly fill your memory card and overstretch your camera's data transfer circuitry.