Resolution-Independent Film Scanning: How Independent is Independent?

By Peter R. Swinson

Any film image may be regarded as having four distinct dimensions: height, width, thickness, and dye or grain density variations. These dimensions all contribute to or detract from the total resolution capabilities of film. This paper attempts to quantify the limits of the film resolution so as to establish practical means to retrieve, in a digital form, all the useful image information from motion-picture film.

Excellent though it is, even film has some limitations in terms of resolution. Any film image may be regarded as having four distinct dimensions: height and width, which determine the surface area; thickness, which contributes to the robustness of the material but also detracts from its resolution; and dye or grain density variations, which determine the image brightness at any point on the film surface.

To the best of this author's knowledge, all films for any particular emulsion type, regardless of their final cut and punched size, originate from a common manufacturing and coating process (Fig. 1). In other words, for a fixed surface area of film the resolution is the same, regardless of whether it is Super 8mm or 70mm IMAX.

Spatial Resolution

As all film of a particular type has the same resolution in the spatial sense, it is only meaningful if we refer to this resolution in terms of lines per millimeters (lines/mm). Modern color negative material will offer, in all colors, up to 70 lines/mm at 100% resolution, falling at 150 lines/mm to less than 10% resolution. Film manufacturers do not expect this figure to significantly increase over the foreseeable future. Even if the figure improved dramatically, would we get better and sharper images? This is debatable, as the current motion-picture shooting lenses are already hard pressed to match modern film resolution. Further limits to spatial resolution occur due to the steadiness of the taking camera mechanism; while such film movement during exposure is minute, it can affect the overall resolution slightly.

In terms of spatial resolution there are limitations in the film material itself, the taking lenses, and possibly the camera transport mechanism (Fig. 2).

It is fairly safe to assume that film images are unlikely to offer any useful information greater than about 100 lines/mm. Converting 100 lines/mm into pixel equivalents (Fig. 3) provides roughly the following pixel counts, shown in Table 1, beyond which nothing is gained. Therefore, it can be seen that film itself is not spatially resolution independent, as there are limits beyond which no significant advantages would be obtained.

Densitometric Resolution

If we now consider the fourth dimension of film, the parameter that really differentiates this wonderful

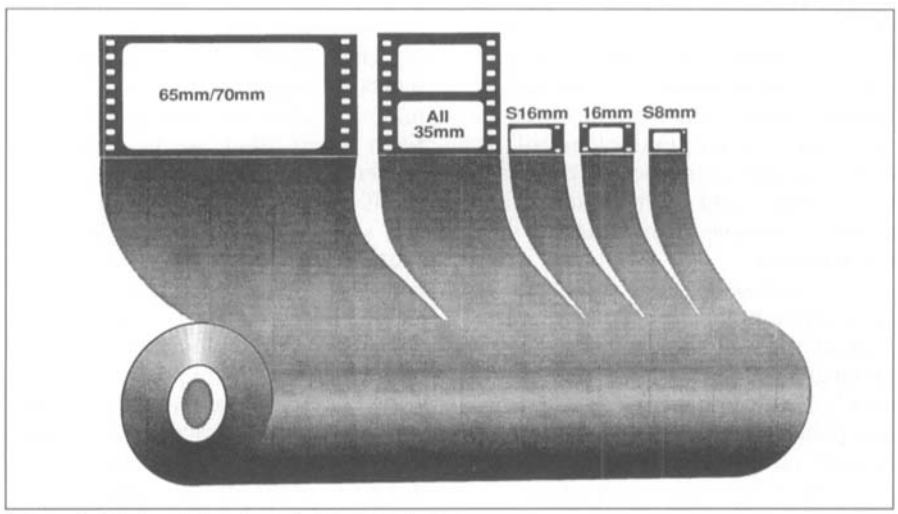

Figure 1. Motion-picture formats have a single source.

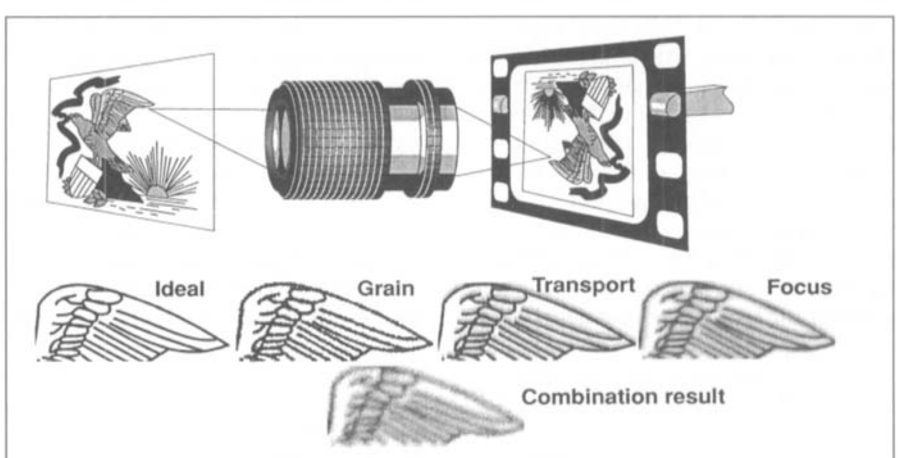

Figure 2. Lens and camera limitations.

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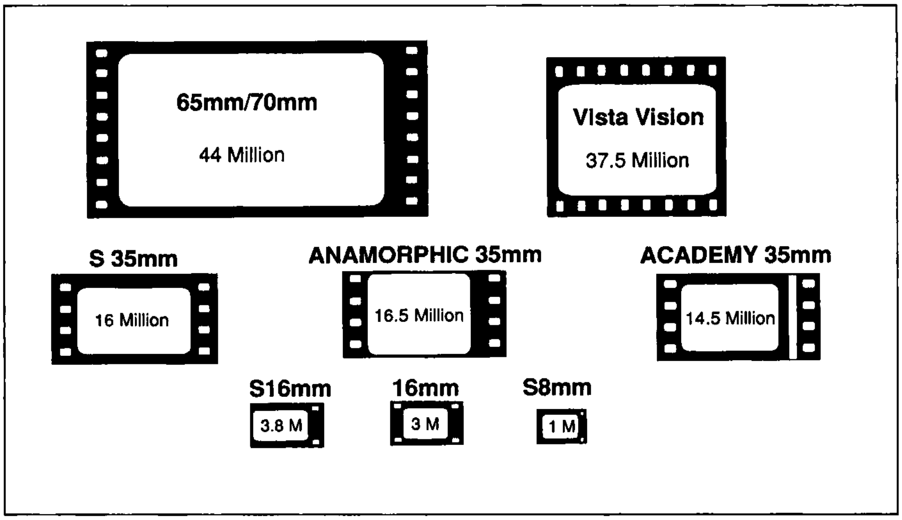

Figure 3. Film formats — 100 line/mm frame pixel count.

material from video is image density. The resolution of this density can be regarded as almost infinite. It is a common assumption that because film has a certain density range, the density resolution is fixed (Fig. 4). This assumption evolves from the fact that we tend to consider only the extremes of density by assuming that because a fixed range exists it must have a fixed number of bits.

The film density range may well be limited; negative, for example, can be expressed as having a range of density from 0.05 to 1.8, or about 64:1. Today analog-to-digital (A/D) converters whirl away and convert 64:1 into 6 bits. However, this small total range is spread over a linear set of changing densities, as there are no digits in a film image. The creation of the image is analog, and the resulting chemical density is also analog.

It is the density discrimination that is all-important in film. Such discrimination shows well in subtle shades at any viewed density. Good examples at either end of the density range are wispy clouds in an almost white sky and the shadow detail that can still be observed in very dark scenes. The human eye is an excellent discriminator of such shading detail, and film comes in a close second. If this were not the case, we would have all moved over to video years ago.

Is film density discrimination resolution independent? Well, almost. The limit is largely chemical and is formed from two contributions (Fig. 5). First, the grain or dye image is discontinuous, which leads to effective dither frame to frame. Secondly, the coating and developing processes are not perfect, and this leads to minor differences in density inter- and intraframe, which tend to be shown electronically as minor flicker noise. Both effects are, to all intents and purposes, purely random.

Taking all the density matters into consideration and working from a material with the greatest discrimination, negative film, there is little to be gained from digitizing the levels by more than 14 to 16 bits. In many cases 12 bits may be adequate. Some advantage may also be gained by nonlinear quantization; however, this subject would require very careful study to ensure that such quantization did not compromise the image in other respects.

Taking the pixel count for each format and applying 12 to 16 bits for each pixel in each of the three colors — red, green, and blue — we can establish an approximate digital storage requirement for each film frame, and for every second in time based on a real projection rate of 24 frames/sec (Table 2).

This data shows the incredible capacity of motion-picture film. No doubt many will mutter that compression could considerably reduce this data requirement, but we are talking here about cloning everything that is on the film, so compromises are not

Table 1 — Film Formats (Frame Pixel Count)

Format	Width	Height	Total
S 8mm	1200	850	1 million
16mm	2000	1500	3 million
S16mm	2500	1500	3.8 million
35mm			
Academy	4500	3200	14.5 million
S 35mm	5000	3200	16 million
Anamorphic 35mm	4500	3700	16.5 million
VistaVision (35mm)	7500	5000	37.5 million
70mm	9800	4500	44 million

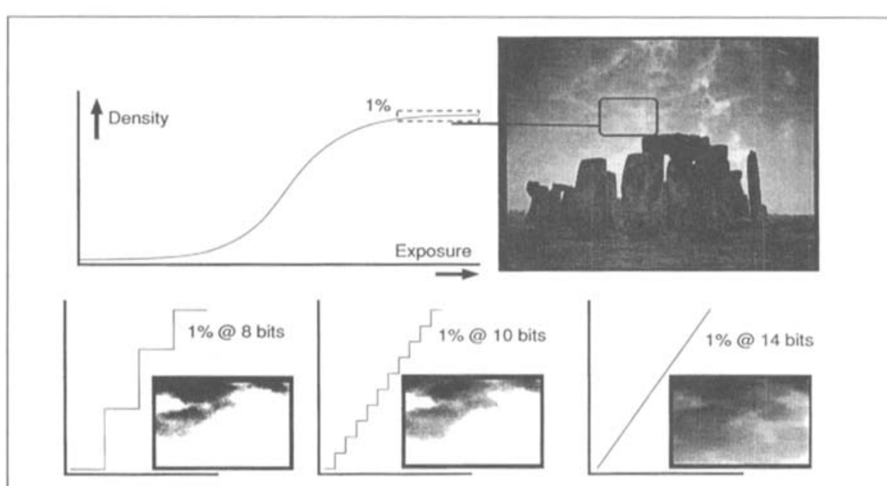

Figure 4. Film density at various exposures.

Table 2 — Film Formats (Mbytes for each Frame and Second)

Format	Pixel Count	Bytes/Frame	Bytes/Sec
S 8mm	1 million	6 million	144 million
16mm	3 million	18 million	432 million
S 16mm	3.8 million	23 million	552 million
35mm Academy	14.5 million	87 million	2088 million
S 35mm	16 million	96 million	2304 million
Anamorphic 35mm	16.5 million	99 million	2376 million
VistaVision (35mm)	7.5 million	225 million	5400 million
70mm	44 million	264 million	6334 million

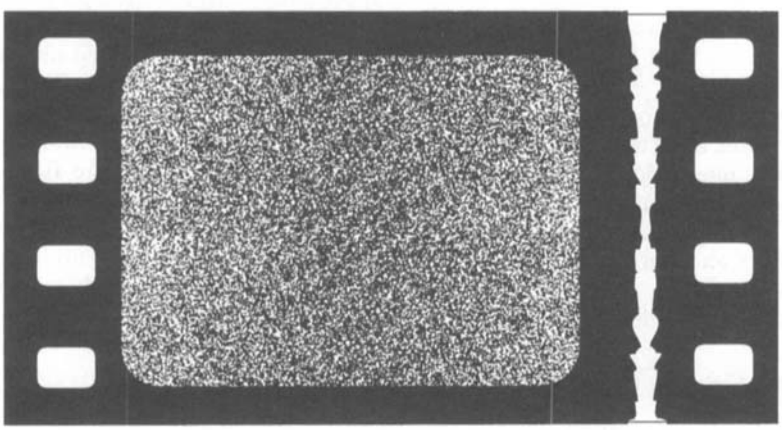

Figure 5. Random grain and chemical shading.

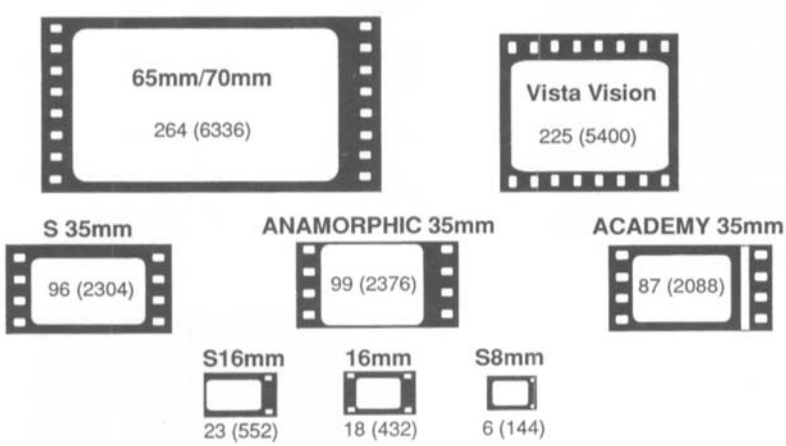

Figure 6. Number of Mbytes needed for each film format.

being taken into consideration. It is interesting to note that one second's worth of 16mm transfer would only just fit onto a multimedia CD-ROM, and a 30-sec commercial shot on 35mm negative could require almost 70 Gbytes of storage when all the film detail is to be preserved. These figures also show that real-time transfers are currently extremely difficult to achieve; also, such equipment would be prohibitively expensive without compromising quality.

All of this assumes that we are trying to provide an electronic clone of the original negative, rather than to fit the film to an electronic system that currently satisfies technical needs. Trying to fit the film to current needs would, of course, be potentially less severe than providing a clone of the film; however, current needs will not be sufficient in the very near future, for progress demands ever-increasing quality.

Resolution-Independent Film Scanners

Several high-resolution film-to-digital-data transfer systems exist or are currently under development. Rank Cintel is researching such a scanner based upon the film parameters previously described. Flying spot systems for high resolution remain ideal for real-time transfer and optical effects; such designs have been considered and are achievable. However, their price excludes them from consideration at the present time.

Rank Cintel Scanner

Rank Cintel is well known for telecines, its attention to film-transport steadiness, and its ability to retrieve the best detail from film. Current research into high-resolution scanners indicates that the film should be treated in a manner very similar to that used within the top film effects houses, by transporting and using printing optics in an identical manner to optical effects printers. The use of such principles ensures that the film is transported with a precision that exceeds the taking camera by at least one order of magnitude, and the optical precision exceeds that of the original camera optics. This also offers a system that equates or exceeds the quality required for the most demanding optical effects.

Conclusion

Film remains the chosen source material for the highest quality images; however, we should not lull ourselves into believing that it is entirely resolution independent. Larger formats used correctly will take us nearer reality — but at what cost? Our world is built around Thomas Edison's and George Eastman's 35mm format, and it is mainly by the use of this format that we all prosper.

Perfection is the goal, and every day we all get a little closer. Perhaps next year we will be discussing subatomic or subelectron resolution. All things are possible, but we must keep a certain practicality in mind or we shall all be searching for means to digitally store more data than the universe can hold.