White Paper

The Evolution of Resolution

The future of film scanning

The post production industry is changing at a dramatic pace. With digital cinema on the horizon and the move to full film-resolution digital effects, the film scanner world has changed dramatically.

SD video is giving way to HD and data. Linear videotape is fast being replaced with HD and data disk systems, and Digital Cinema is purported to be the next revolutionary stage in the visual entertainment field. While regular video is still in demand, High Definition video is already in place, with most all of today's scanner manufacturers catering for high quality transfers to HD. And while HDcam and similar are being touted as the future of moving image acquisition, many remain sceptical. Film remains the ultimate image capture medium and will remain so as long as scanning techniques preserve its benefits as the industry changes.

The future is film

While some are suggesting that HD capture may replace film at the camera acquisition stage Cintel believes that to do so would be a dangerous move in limiting the future quality of images for the large screen.

Film has much to offer over the limited resolution of HD video and means to obtain this greater film resolution in a smaller bandwidth than HD are on the horizon. Film's vastly superior dynamic range compared to the limited range of all video systems is well understood. What is less understood is the potential resolution of film, especially 35mm. So, what determines the maximum resolution of film ?

The maximum resolution of film

Firstly, the film format, 35mm can accommodate 6K resolution. Secondly, the quality of the taking lens has a dramatic effect on resolution. While today's zoom lenses are extremely good, the ultimate quality can often only be achieved with prime lenses. Good prime lens can achieve a solid 4K on the film and still resolve some information at 6K.

Film as a source image greatly exceeds the quality of HD, it therefore makes an ideal source for HD and can be dramatically manipulated during transfer to obtain almost any desired look without the image "falling apart".

The downside to film is projection, where the losses incurred at each print stage, and the projection lens degrade the image quality. The printing process itself typically reduces the resolution of film, to about 2K even at the inter-positive stage, with further minor reductions at each subsequent print stage. This degradation, plus the losses in most projection lenses means that we may never see, from 35mm, more than about 1.5K resolution on the cinema screen.

However the future for film is interesting. Already there are digital projectors capable of solid 2K resolution, and the development of 4K projectors is on the way.

Maximum resolutions in film scanning

So what determines the maximum capture resolution of any scanning device? For CCD Line & Area Array Scanners the objective lens; normally a prime on Line Arrays and a zoom on Area Array devices; set the optical limits. The CCD photo-sites set the sampling limits and the beam splitter will have some effect on final resolution.

For Flying Spot scanners, whether they are CRT or laser based, the resolution is determined by two features only; scan spot size and the objective lens. It should be noted that when data scanning film with CRT based scanners, neither the detectors, nor the signal path bandwidth has ANY EFFECT on resolution. Cintel's present scanner range achieve up-to 4K resolution from 35mm film, by utilising a CRT scan spot of 30um, which is optically reduced through a high precision 11 element lens to 7um on the film plane.

While scan rates could be real time, just by increasing raster scan speeds and channel bandwidths, even with just SD bandwidths we can scan 2K @ 6fps and 4K @ 1fps scan. In the near future we aim to provide rates 3 to 4 times faster.

Based on Cintel's 35mm 4K scan capabilities, we show that original camera negative has detail well above 2K, indeed 4K may not be the limit:

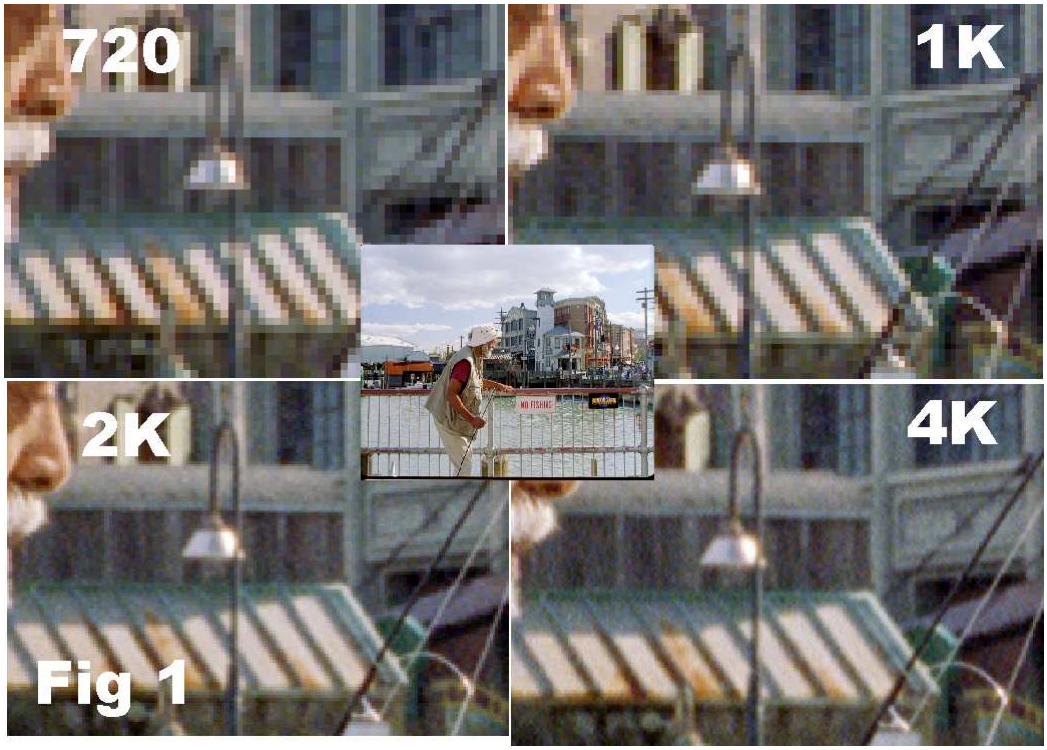


Fig 1 Examples, all from original camera negative, show the results at varying data scan resolutions.

While 2K resolution is adequate for HD video and film IPs, it is not for sufficient for camera negative. As seen here, there are alias caused on sharp edges, because the sampling is less than the film resolution. On the 4K-scanned example, note the lack of hard-edged pixels. This scan is "smooth" because the scan sampling is now matched or exceeds the film's resolution.

So that's the good news. However as data file resolutions increase so do file sizes.

Comparing resolutions, file sizes and throughputs

RAW DPX 10 bit log file sizes

	Mbyte for each:- Frame	Second	Minute
SD	1.6	38.4	2.3Gb
1K	3.2	76.8	4.6Gb
HD	8.2	197	11.8Gb
2K	12.5	300	18.0Gb
4K	50	1.2Gb	72.0Gb

Fig 2

Fig 2
This table shows how big some of the files become.

Maximum Data Port throughput

	Frames per second 100BaseT	Hippi	Fiber	LVDS	HSDL	GSN
SD	6.3	43.8	62.5	70	188	500
1K	3.2	21.9	31.3	35	94	200
HD	1.2	8.5	12.2	13.6	36	98
2K	0.8	5.6	8.0	9.0	24	64
4K	0.2	1.4	2.0	2.3	6.0	16

Fig 3

Fig 3
There are many proposed data ports over which to transmit files - here is a selection of estimated maximum throughputs.

While we would all prefer to scan camera negative at the highest resolution, file sizes become a problem.

However this may not necessarily be the case, and it would appear that the higher the initial scan resolution, the easier it is to compress the image.

Compression v non-compression

Before we dismiss compression as useless for film quality images, let's look results. Cintel has performed considerable research into making 4K a usable data format, making the data files a manageable size. This is the experimental route we took:

Fig 4
Firstly we scanned 35mm camera negative at 4K, and stored DPX 10 bit log files in our Postware Data system.

These were converted to linear files, color corrected, then compressed and subsequently de-compressed.

A set of uncompressed files was also reserved. We split screened the images digitally, recorded them back to an inter-negative and printed the film.

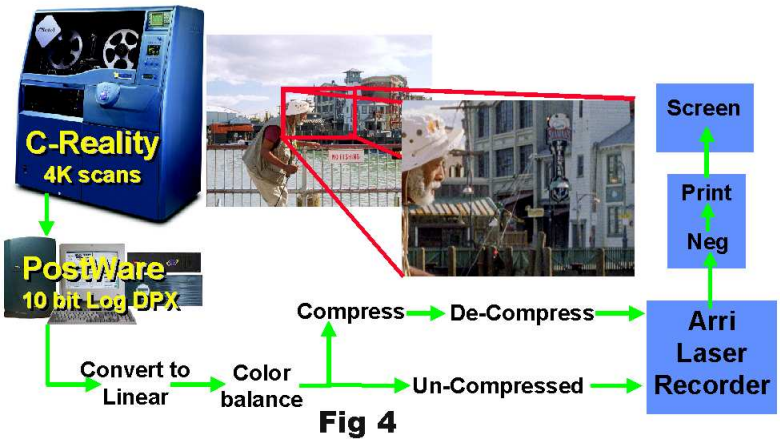


Fig 4

Because we believe today's printing and projection limits visible resolution to about 1.5K we also recorded and printed the same image digitally magnified by a factor of 4.

Even with the limits of film projection, detail at effectively 6K resolution can be seen. We have managed to fit two 4K frames onto a standard floppy disk . That's about half a megabyte per frame as a 24 bit image and one megabyte a frame as a 48 bit image.

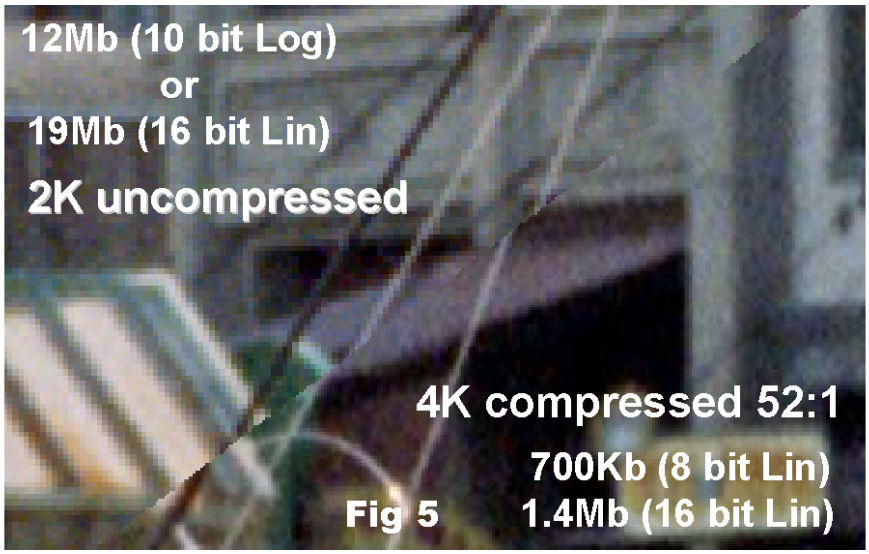


Fig 5
Here is an example of 2K uncompressed vs 4K compressed 52:1.

These images are designed for full theatrical screen size demonstration.

For a better effect please view the images on the web site: www.cintel.co.uk.

Fig 6
This is the frame rate advantage compared to the degree of compression. It is based on 48 bit linear files. In the extreme with GSN 20 times speed transfer would be a possibility!

While storage is becoming less expensive by the day, the volume is still considerable when dealing with high-resolution files.

Compressed 4K Frame Rates (16 bit)

	4K	4K 5:1	4K 10:1	4K 26:1	4K 52:1
100baseT	0.1	0.5	1.0	2.6	5.2
Hippi	1	5	10	26	52
Fiber	1.3	6.5	13	34	68
GSN	10	50	100	260	520

Fig 6

Storage for 4K compressed files
(Based on 75 Mb uncompressed @ 16 Bit)

	4K	4K 5:1	4K 10:1	4K 26:1	4K 52:1
30 sec	54Gb	11Gb	5.4Gb	2.4Gb	1.2Gb
30 min	3.2Tb	640Gb	320Gb	123Gb	61.5Gb
60 min	6.4Tb	1.2Tb	640Gb	246Gb	123Gb
120 min	12.8Tb	2.6Tb	1.2Tb	492Gb	246Gb

Fig 7

Fig 7
These are the savings that could be achieved with 4K compression techniques.

Think of it, 2 hours of 4K full film resolution, on less than a quarter of a Terabyte of storage. Of course, once compression of linear 48 bit files is used, a log to linear conversion stage is also eliminated.

Fig 8
Here we look in detail at the effects of compression on different sampling resolutions to understand why this all works. At 2K, the compression causes considerable blocking. At 4K there is very little blocking. Note that the compression artefacts become much worse as the sampling resolution drops.

Tests indicate that even 52:1 compression of 4K offers better images than uncompressed 2K. Further the 4K compressed images may be good enough for most film work.

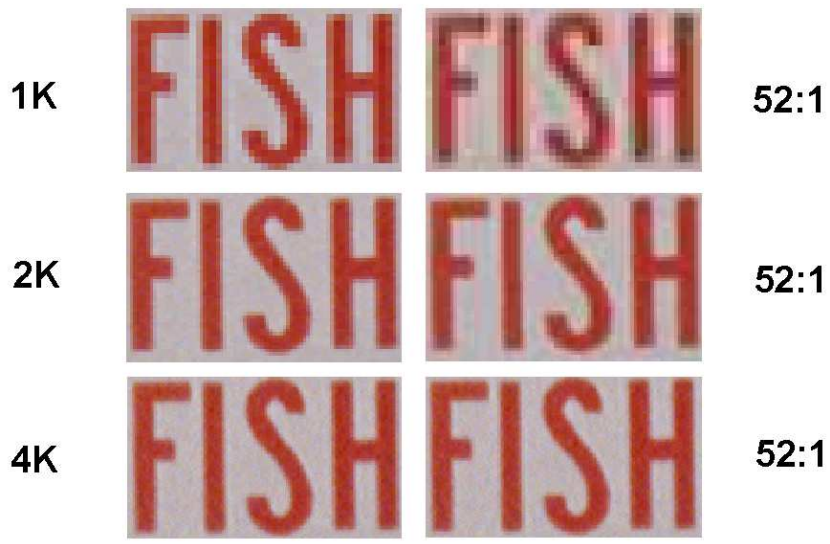
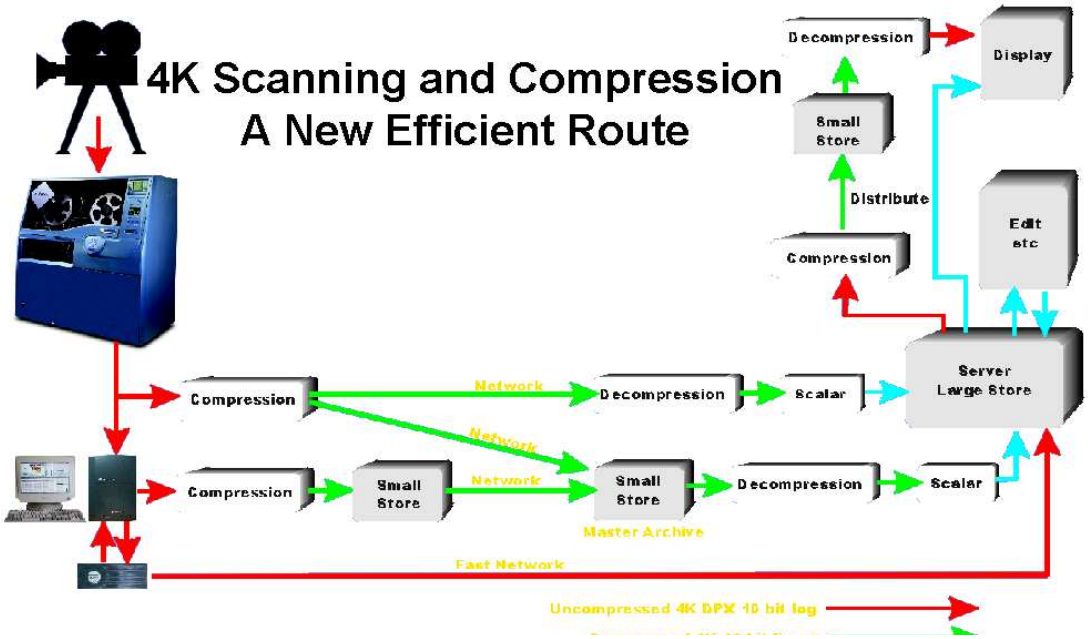


Fig 8

Compression – practical steps to creating an archive and projecting for D Cinema

Compressed 4K files could be the REAL Archive, with no need to ever transfer the material again. Smaller files allow very fast transmission over the simplest network, including “real time” transfer to work station. This would offer offline images availability immediately. A further advantage is that the compression could allow us to keep the files in 32-48 bit linear space rather than 30 bit Log space that is presently needed to reduce file sizes and improve speed. It may sound expensive today, but prices will fall dramatically if demand rises. With economical 4K scanning, Film Studios could at last consider an entirely electronic post process, so long as they mastered on film.



The sequence may go like this: Scanning the camera negative, 4K digital effects and edit, to produce the 4K digital intermediate, from which, essentially “loss-less” 4K digital prints could be distributed to the 4K Digital Cinemas, and, through the entire process, the resolution will remain the same, 4K. Uncompressed 4K versions could still be available at the scanner site and selection of “difficult uncompressed scenes” could still be called over fast networks.

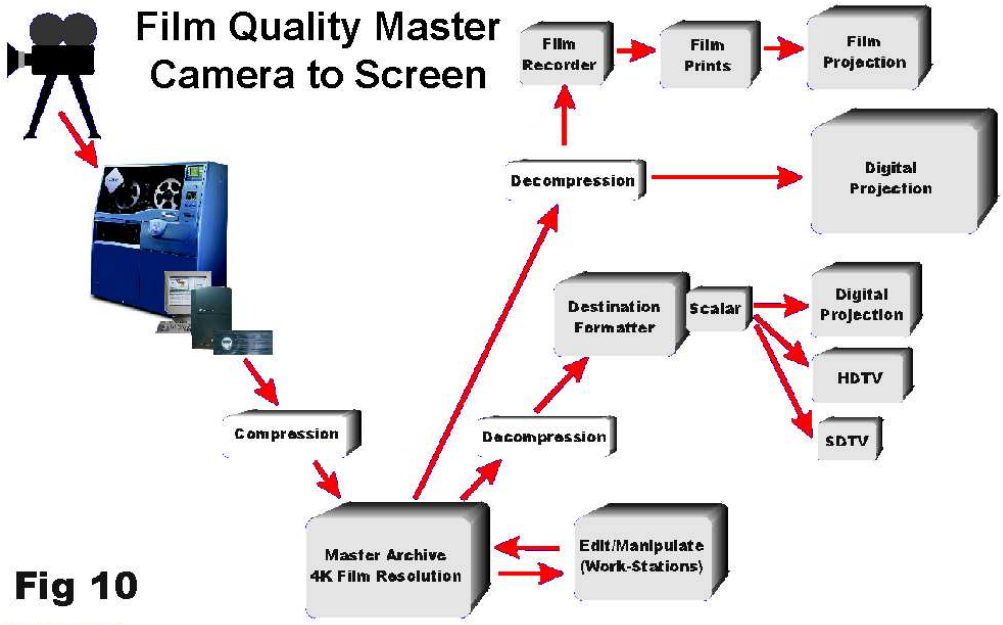


Fig 10

While we would not propose that compression be reused at every stage of effects or restoration processes, we do propose that this maybe a solution at either end. In other words from the scanner to master archive, and maybe from final master to D Cinema. Remember no one has ever seen 4K resolution from 35mm in the Cinema, because all the print processes conspire to limit the resolution to less than 2K.

With digital projection we have the opportunity to present full 4K resolution from 35mm film, that would match 65mm projection and maybe even Imax. What's more the studio will have what they have always wanted - a digital master that faithfully represents everything that was on the original film image, except of course the scratches and dust that are caused by physical film handling during the edit stage. Also scaling down for all other versions can be obtained from the film quality original without re-transfers.

So, now consider whether shooting features on HD video at less than 2K, is really the way of the future! Our examples show that 2K from original camera negative it does not do it justice.

Think of it, an entire film archive could be shown at almost Imax quality, and what of those shooting on Hdcam or similar, they will not even get close to offering such an experience!! All of this is food for thought. Cintel, having researched and proposed this scenario will be working with our customers to make 4K high-resolution data storage and economical "transmission" a reality.

Conclusion

We would suggest that the way forward is to shoot film, scan 4K, save the archive effectively with lossless compression. All to ensure that you preserve a digital master that is future-proof.

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April 2002

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