digital light

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Digital and networked media are now very much the established media. They still hold the promise of a new world, but sometimes this new world looks as much like a complex form of neofeudalism as a celebration of a new communality. In such a situation the question of what ‘media’ or ‘communications’ are has become strange to us. It demands new ways of thinking about fundamental conceptions and ecologies of practice. This calls for something that traditional media disciplines, even ‘new media’ disciplines, cannot always provide. The Fibreculture book series explores this contemporary state of things and asks what comes next.

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The cover is a visualization of the book's text. Each column represents a chapter and each paragraph is modeled as a spotlight. The colour reflects an algorithmic assessment of the paragraph's likely textual authorship while the rotation and intensity of the spotlights are based on a paragraph's topic ranking for "digital light". It was made with Python and Blender. © David Ottina 2015 cc-by-sa

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CHAPTER 3

HD Aesthetics and Digital Cinematography

Terry Flaxton

This chapter is accompanied by a series of online interviews entitled 'A Verbatim History of the Aesthetics, Technology and Techniques of Digital Cinematography'. This online resource seeks to circumscribe and circumlocute the wide variety of interests and usages of incoming digital media with specific relation to the effects of increased resolution being offered by emerging digital technologies and can be found here: www.visualfields.co.uk/indexHDresource.htm

In April 2007 at the National Association of Broadcasters convention in Las Vegas, High Definition Video changed forever. Whereas previous HD cameras had cost half a million dollars, Jim Jannard, a sunglasses manufacturer from Canada, had managed to develop a new camera called the 'Red One,' retailing at $17,500. This development signalled a change in the production of High Definition as it had been first conceived and named. The original title—'High Definition'—was meant to signal a change from standard resolution digital video and align the new technology with film, giving it more of a sense of quest than analogue or digital video, more of a sense of flight, a sense of the arcane and the hidden, thus producing something to aspire to and engendering a sense of being elite—very important for the Directors of Photography, those captains of the ship heading towards the image horizon and in turn, evoking some of film's prior sense of mystery. Now we are in the stable years of

'HD', the title 'HD' has become misleading, mainly because it refers to a line structure that was pertinent to the analogue age (and related to television) but which no longer appropriately characterises the current aspirations for the medium.

A High Definition Image to Recall

I want to introduce an image that may be useful when thinking of HD: as the light falls at dusk and you are driving along, you might notice that the tail lights of the car in front of you seem much brighter than in daylight, and the traffic lights seem too bright and too colourful. The simple explanation for this phenomenon is that your brain is switching between two technologies in your eyes. The first technology is the rods (inherited from our distant ancestors), which evolved for the insect eye to detect movement, and are numerous at around 120 million. Through them you see mainly in black and white. The second technology is much more sensitive to colour: these are the cones, which are far less numerous at around 7 million.

Colour is a phenomenon of mind and eye—what we now perceive as colour, is shape and form rendered as experience. Visible light is electromagnetic radiation with wavelengths between 400 and 700 nanometres. It is remarkable that so many distinct causes of colour should apply to a small band of electromagnetic radiation to which the eye is sensitive, a band less than one 'octave' wide in an electromagnetic spectrum of more than 80 octaves.

Human trichromatic colour vision is a recent evolutionary novelty that first evolved in the common ancestor of the Old World primates. Placental mammals lost both the short and mid-wavelength cones. Human red–green colour blindness occurs because, despite our evolution, the two copies of the red and green opsin genes remain in close proximity on the X chromosome. We have a weak link in our chain with regards to colour. We are not 4 cone tetrochromats; we have three and in some cases only two—in extremely rare cases we have one.

So, there are two technologies—rods and cones—between which there is a physiological yet aesthetic borderland. Keeping this idea in mind, if we apply the potential misreading of eye and mind not to colour, but to our ability to recognize different resolutions, then a similar potential sensorial confusion is possible in the higher resolutions of which we are now capable. In my own experiments with capture and display, it is becoming apparent that a viewer experiences a sensation similar to the illusion that there is more colour at dusk when a certain level of resolution is reached. At that borderline between the lower resolution and the higher resolution, a fluttering occurs as we engage in this step-change of resolution. I have found that at the lower level there is less engagement, as measured by the duration the audience is willing to linger with an image, and at the higher resolution there is more engagement. This is evidence of a switching between two states in the suspension of our disbelief—with higher resolutions eliciting more visual fascination. What is really interesting to me, as an artist, is the boundary between the two states.

The Figures

After the invention of television, it took many years to be able to record the analogue video image. This was finally accomplished through creating a scanned rasta of lines and inscribing what information was present in each line. This was the strategy of analogue video in its two main forms: PAL and NTSC. When computers began to take over, scanning became obsolete (having only been necessitated by the limitations of magnetic control of electron beams and glass technology at that time); so a form of inscribing and recording the information that was independent of the scanned rasta but was grid-like—digital in form and mode—took over. This became the now familiar grid of pixels that every camera sensor has. A progressive image sensor is like a frame of film in that it is exposed in one go, unlike a scanned image, which takes time. But there are many issues with the technology that make it unlike film (like needing to empty a CCD of charge, line by line, or a CMOS chip in one go). Each chip is constructed of many individual photosites that are single light sensitive areas. These then produce information in the form of packets of data that are in turn represented on screen by a changing luminosity and colour identity via a pixel of display.

But let us step back to the moment when analogue video began to give way to the first digital forms. Digital Video was then transforming analogue technology and this moved us closer to High Definition technology. It had 720 x 576 pixels to emulate the 625-line system in analogue video (in PAL at least). It required anamorphising to enable a 16:9 ratio from a near 4:3 pixel count. It confused many of its early adopters because it seemed to disintegrate through multiple copies—yet of course Digital Video was heralded as non-degenerative. The fact was that it was only partially digital, but it gave us a run for its money.

The earliest forms of High Definition were analogue at around 1250 lines, but being on the cusp of the digital revolution, HD soon abandoned the early analogue HD forms as it became digital. In economic terms this meant that the early European systems were being financially trounced by the Japanese and American systems, so the standard eventually became 1920 x 1080 pixels (which had a relationship to the analogue NTSC format).

Standard HD is known as having 2k resolution because it has a resolution of 1920 x 1080 pixels (1920 is near 2000). This has a 16:9 or 1.77:1 aspect ratio, which is common to LCD, LED and plasma television design. Cinema style HD has been called Electronic Cinematography—it is also 2k but has 2048 x 1080 pixels (or sometimes 2048 x 1024). This has a 2:1 aspect ratio. The academy version of 2k has 2048 x 1536 pixels, which is 4:3 aspect ratio. So there are varying requirements concerning the number of pixels in an electronic cinematographic image—agreements still have to be made as to exactly what numbers are involved though this is getting closer with the Academy Colour Encoding System (although this is primarily a system to determine standardised colour through different media, it will have a knock on effect with regard to resolution). There is also one other important difference between Standard or HD resolutions (which are governed by proprietary formats) and Electronic Cinematography. Proprietary forms of HD are generally processed (or data reduced and processed) in camera, whilst Electronic Cinematographic forms are processed mainly in the post-production house. 4k is 4096 x 2160 pixels (2:1) or 4096 x 2304 (16:9), and 8k is 7680 x 4320 (16:9)—this last is NHK's Super Hi-Vision. In conversations with leading designers in the subject area I have established that far higher resolutions than 8k are in development.

It is possible to record most of these formats in a compressed version on a form of memory card, but currently, the highest level of 2k HD image capture requires recording onto solid state discs—and not just any solid disc, but a Redundant Array of Independent Discs—a RAID (the exception is Sony's SR deck, which records data on tape). If you want to record 1920 x 1080 pixels uncompressed, then you need read and write speeds of *over* 440 Megabytes (Mb) per second. The average old style hard drive reads and writes at around 35 Mb —hence you need quite a few of these (though solid state drives record much higher rates you still need several of these too). To understand the idea of the RAID, imagine the following: If I throw you a ball, you might be able to catch it. If I manage to throw you twenty balls at the same time, you have no chance. If I throw twenty balls to you and another nineteen friends—you have a chance of catching them. A RAID Array uses a group of discs to catch large amounts of data.

Criteria for Digital Cinematography

Until recently many manufacturers used small chips of around half to two thirds of an inch in size—each camera used three chips for three colours to reconstruct a colour image (red, green, blue). The chip size was a hangover from 16mm film that generated large depth of field from the smaller optical pathway. When Red Cameras introduced the Red One it began with a 35mm-sized single sensor that used a Bayer filter to extract colour information. Bryce Bayer invented this system for Eastman Kodak in 1976—primarily to extract information from scanned film images.

With the above in mind here is what I consider to be the governing principles for Digital or Data Cinematography:

> a) The optical pathway is 35mm or above (derived from technical and industrial limitations possible at the time of origination for manufacturing photo-chemical negative).
>
> b) It generates a progressively based image flow relating to a specific time-base as opposed to an interlaced image flow (one full frame of information at a time rather than a field-based workflow).
>
> c) Like one of its predecessors, film, it holds the image in a latent state until an act of development (or rendering) is applied—but unlike film it is non-destructive of its prior material state.
>
> d) Its capture mechanism, though generating a non-destructive, non-compressed data pathway from which an image can be reconstructed, does not have this as its sole intent as a medium or method of capture.

These latter three qualities are also base characteristics of many other developing digital technologies—for instance real-time mapping of environments requires a capture of infra-red imaging sources (cameras used as sonar devices) running at around or above 25 fps. Using this criteria, Digital Cinematography is about more than just capturing images—it's a portal onto the digital landscape so far unexplored due to its apparent function as an image capture medium.

What Was the Future, Is Now the Present

The future is governed by Gordon Moore's Law, formulated in 1965, which proposes:

> The complexity for minimum component costs has increased at a rate of roughly a factor of two per year … Certainly over the short term this rate can be expected to continue, if not to increase. Over the longer

> term, the rate of increase is a bit more uncertain, although there is no reason to believe it will not remain nearly constant for at least 10 years. That means by 1975, the number of components per integrated circuit for minimum cost will be 65,000. I believe that such a large circuit can be built on a single wafer. (Moore 1965: 114–17)

In 1975, Moore altered his projection to a doubling every *two* years (Moore 1975: 11–13).

In the early 1990s I first came across analogue HD systems (including the European MAC system which used 1250 lines). In 1999 I shot a short on the Sony 900, which was post-produced by Du Art in New York and then output to 35mm for display at festivals. In 2003, NHK, or the Japan Broadcasting Corporation, conducted an experiment that linked a prototype 8k 16:9 aspect ratio camera to 18 one-hour data recorders. The subject of the test was a car ride lasting three minutes. In order to capture it, the SR data recorders ran so fast that they went through one hour's worth of recording during the three-minute shoot—all 18 of them. The resolution of the projected image was immense: imagine a computer display set at around 1280 x 1024 pixels—then imagine a screen of some twenty-seven feet long with the resolution proportionately more detailed. A little more than 100 years earlier, this technological moment had echoes of the Lumière Brothers' screening in January 1896 of a train arriving in a station. At the NHK screening, the Japanese audience were reported to have found the experience so overpowering that many of them experienced nausea. Both of these tales are at the same time apocryphal, yet pleasing.

So now we can place a computer image on a screen of cinema proportions with equivalent or more than cinema resolution (at the time of correction Alfonso Cuaron's Gravity has opened to wide acclaim – a feature of over 90 per cent computer graphic content). So, imagine what it would look like—in fact what it would *feel* like, if the very high density of pixels shot in the NHK experiment were then displayed across that screen as cinema—in the NHK experiment the possibilities of deep engagement and belief in the experience seem to have lead to a physiological reaction. Since this experiment, Super-Hi Vision has been streamed live between Tokyo and Osaka—but of course that act required a high amount of compression.

Technology and Compression

The high levels of data produced in creating digital cinematographic images should beg a primary question in the reader's mind with regard to how we actually achieve data capture. Any serious understanding of High Definition / High Resolution technologies requires a basic understanding of 'compression' (and this is without a deeper discussion of ever increasing colour bit depth where veracity of colour and a larger data collection is required to pursue the twentieth century's primary aesthetic project, that of realist and hyper realist intent). This question should be: How do we accomplish so much with so little?

Light is focused through a lens onto a charged coupled device or sensor, which then emits electrical impulses that are reconstructed as data. Very early on in video production, a question arose for designers when far more data was generated through this process than was recordable. It was from this problem that the idea of throwing 'unnecessary' data away took hold. A strategy that commercial producers utilize is that of adopting the idea of GoP structures to compress images—and this practice underpins not only low-level HD recording in camera, but transmission of images over the Internet.

GoP is short for Group of Pictures. The first and last frame in a group of pictures contain all the information: each succeeding picture only contains the changes in the information. If a person is photographed against a background, there is no need to resend the background information again and again—only the information about head, mouth and eye movements. You can see the affects of GoP structure effects when you watch the blocky artefacts in DVD or Blu-ray, or HD transmission occurring—there is a regular beating in the change of the blocks. HDV, P2 and AVC cameras use this system to record images and it is often criticized for being unable to handle motion well. Clearly the shorter the GoP structure, the better this system will handle motion.

The traditional photographic camera manufacturing companies have recently got on the bandwagon, taking advantage of the convergence of still and motion picture imaging. Some DSLRs, but not all, had the benefit of a 35 sized single sensor—but with limited writing speeds were restricted to GoP structure compression. By the end of 2011 Canon brought out the Canon C300 to fully enter the motion imaging market place. However, in an act that could be seen as an attempted spoiler, Red introduced the Scarlet X on the same day at half the price and like its antecedent, the Red One, with full frame recording. Some fans of Red complained that the Scarlet was simply a diminished version of Red's Epic camera, one that did not value the rapid developments in the area. Others appreciated the gesture of the possibility of the mass availability of the technology.

Other motion image manufacturers lead by Red, Arri, Panavision and now joined by Sony and Panasonic, realize—mostly through pressure by the cinematographic community—that one of the baseline rules necessary to achieve True Digital

Cinematography is to keep all of the data in order to properly describe what is in front of the lens. At the time of writing there are no longer any manufacturers of photo-chemical based film equipment.

So how have impossible amounts of generated data now become recordable?

Wavelets

An accumulation of data in a camera is a representation of the original scene and all representations have levels of veracity with regard the original. Previous SD and HD cameras use a software technology based on Jean Baptiste Joseph Fourier's Discrete Cosine Transforms (DCTs), which break up the image data into tiles, so that each can be treated independently. Recently though, we have seen the arrival of Fourier's Wavelet Transforms. The theories involved were in place by 1807 but not truly understood until about twenty-five years ago. Wavelets have helped prise open a Pandora's box. Here is a description by the astrophysicist Amara Graps:

> Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. Wavelets were developed independently in the fields of mathematics, quantum physics, electrical engineering, and seismic geology. Interchanges between these fields during the last ten years have led to many new wavelet applications such as image compression, turbulence, human vision, radar, and earthquake prediction. (1995)

Discrete Cosine Transforms are a sort of 'one-size-fits-all' response to data—a thuggish response requiring intensive computation. This is in contrast to Wavelet Transforms, which interrogate the data coming through them and find the best response from within their algorithm. In effect they intelligently address the data to get the best out of it, while using less computational power. As one Director of Photography put it on the Cinematographers Mailing List: 'ummm, wavelets good, DCT bad.'

Contemporary cameras and post-production systems have been designed with DCTs in mind, and the manufacture of the relevant devices, cameras, proprietary editing and storage systems has been designed and marketed to recoup the large amounts of costly research that has been expended by big corporations. It has simply not been in the interests of the bigger corporations to switch over to the new, more elegant technologies. Yet the pressure exerted by the maverick Red Camera Company had telling effects on corporations like Sony, who marketed the F23 and the F35, followed by Arriflex with their Alexa camera. Sony's naming system bears some investigation: The F23 used a two-thirds inch chip, the F35 a 35mm sized sensor and in 2011 Sony launched the F65, a possible reference to 65mm, which uses an 8k chip that generates a truer 4k image. To obtain a true register at such resolutions one must take two samples to derive a value—this is know as the Niquist Shannon Sampling Theorem—an important factor in Modular Transfer Function or MTF.

With a nod towards Ivan Illych and his studies around systems disorders—in his case with regard to how much allopathic medicine cures and how much illness it induces (known as iatrogenesis), we must also understand that any system has a limiting element within it. In electronics this is referred to as Modular Transform Function.

Modular Transfer Function describes a chain of delivery from capture to display where resolution is defined by the lowest resolution link in the chain (like plumbing where flow is derived from the thinnest of the pipes in the system). For instance in Apple's Final Cut Pro Studio 3, the base architecture limits resolution to 2000 lines. If you shoot 4k, edit through Final Cut and then display on a 4k monitor—the MTF of the system is 2k (however, new iterations of that manufacturer's software and other manufacturers of post software are using resolutions up to 4k and above). With the early Red One's 4k sensor, because of various issues with the Bayer Pattern filter, the MTF of the camera is around 2.8k/3.2k—but of course if you use a lens with less than 2.8k of resolution, then whatever the lens resolution is would then be the limit of the system.

Having said all of the above, a Wavelet Codec, because it deals with curves rather than angles, can intelligently reconstruct large amounts of data from very small samples. Red's own proprietary Redcode 28 can construct a kind of 4k image using only 28 Mb's of recording speed. (RC 36 and RC 42 use 36 Mbs and 42Mbs respectively.) A lossless 2k image should record at 1 gigabyte of data per second (dependent on bit depth etc) so the very idea of recording 4k in 28mbs is astounding and this demonstrates the efficacy of Wavelet Transforms.

The Contemporary Argument About HD Image Control

Currently, film DPs are still brought in to light 2k productions. Though they are becoming familiar with the thinking in Digital Cinematography, previously electronically trained people were brought in to hold their hands; the common ground between the two is the attitude that 'preserving data is all'. At one meeting of the British Society of Cinematographers, there was much wailing and gnashing of teeth as film-oriented DPs stressed their concern over the lack of dependability of the production chains that eventuate in an image. It was argued that it is currently possible to send your data through the same equipment at two different facilities in the same city and obtain different colorations of that image. It has taken 100 years within the practice of photo-chemical film to obtain dependability in the chain of production, and of course the ability of a cinematographer to get that little bit extra, that un-definable advantage in their image making is what adds value to their reputation. However, at the moment, the terrain of Digital or Data Cinematography-based production is still feared because that level of control has yet to be fully realized. Having said that, the American Society of Cinematographers have instituted their Academy Color Encoding Specification and Image Interchange Framework, the intent of which is to introduce full calibration of the process—bringing images from both data and photo-chemical capture, through a reliable framework, right through to display.

Within contemporary cinematographic aesthetics, whether in film, analogue or digital video, or Digital Cinematography, there are a series of tactics used to 'say something' with light. If listed, these tactics become mundane: a warm look for safety and comfort, blue for night, uncomfortableness, then into the greens, sodium or magentas for inducing the uncanny, threat and alienation—and so on. There are some DPs like Vittorio Storaro, who shot *Apocalypse Now* (Francis Ford Coppola, USA, 1979), who step outside of these prosaic colour values. Storaro has his own narrative colour system which works for him and like an extreme system of bidding in the game of Bridge, not too many people can operate it, nor many understand it. Yet many DPs agree, Storaro has 'the touch'. Whereas Storaro works with colour and light, and the physiology of light enmeshed with a psychological narrative, Conrad Hall (born in 1926 and passed away in 2003: *American Beauty*, Sam Mendes, USA, 1999; and *The Day of the Locust*, John Schlesinger, USA, 1975) thought differently to Storaro. His inventiveness and commitment was to the *photographic* within the cinematic arts. As Hall traversed the boundaries of contemporary wisdom about what constitutes good exposure, he influenced a whole generation of DPs. Hall knew that the still image captures something that cinematography rarely does; he was therefore concerned with finding 'the photographic moment' amidst the flow of images. He tried to find the extraordinary within the ordinary. In this quest, Hall pushed film exposure to the limit; this kind of treatment would be ruinous to HD because it does not yet enjoy the exposure of highlights that film does. However, with the arrival of Digital Cinematography this now becomes possible in some ways, though with the coming arrival of Higher Dynamic Range Capture and Display we shall soon be able to capture and display close to the dynamic range of the human eye and brain system.

When I say 'close', within the human system we are capable of seeing fourteen orders of magnitude from the brightest day to the darkest night, but available to us at any given time are five orders of magnitude which we slide up and down the scale of sensory input.

We are all familiar with how our eyes adjust to bright light, or conversely to the dark—that's us making our five orders of sensitivity respond to the spectrum of light which occupies fourteen orders of magnitude in total. HDR Capture shoots two or more simultaneous images, of both highlights and shadows, then merges the result and takes the best of both, in order to display a higher dynamic range image. When displayed on contemporary displays, whether LCD, Plasma, or CRT, the dynamic range of the display space is only between two and three orders of magnitude; hence the description of the image as looking 'plastic' by many DPs. However, the HDR image should be displayed on an HDR display, which is capable of the same level of instantaneous orders of magnitude as the eye/brain. The common response to these new screens is that (to paraphrase) 'it is like looking through a window, with all the attendant clues related to depth'.

Looking Back in Wonder

On a Ridley Scott set in 1983, as he shot the famous 1984 Apple Mac commercial, I was shooting the 'making of' material for Apple (on NTSC betacam video—on tubes). At that time it was not possible to see what kind of images you were obtaining via the medium of film. For that reason the cinematographer, through experience, would be one of the only persons on the set who knew roughly what they would be getting back in the next day's rushes. As we were viewing back our video rushes on our production monitor, checking focus and exposure, I became aware that about 20 people were standing behind us, quietly looking over our shoulders. Usually the film rushes would come back the next day to be viewed by the more select in the hierarchy. The two groups stared at each other—two alien tribes at war—film and video. But this was a film crew that had never before seen what it had been shooting at the same time as shooting it. One of them grinned in pleasure at seeing our footage and suddenly, like the German and British troops in the World War I downing their rifles on

Christmas Day and playing football together, we were friends. From then on they stopped being hostile to us, even sometimes offering to move lights to let us have some illumination—bearing in mind that lights are sacrosanct in film.

Historically, however, in the clash between film and video, the professional film users were seen as artists and craftsmen and video users were seen as artless—even though video art was superseding experimental film at that time. Video was obtainable yet without atmosphere; film was arcane, it was a quest in itself, it had kudos.

Achieving the Filmic Look

In film production, because film stock and lenses eventually had become so sharp, in order to impose an atmosphere, cinematographers have had to constantly distort the colour standards and definitions of film stock. 'Atmosphere', like popcorn, shares a quality that allows the easy suspension of disbelief. If film manufacturers say that development should occur at such and such a temperature, then heating up or cooling down the developer by a few degrees is a means by which the colour, grain or exposure may be changed.

Here is the rub for Digital Cinematography: to get a *look* from a clinically clean medium you have to distress the image and therefore lose data, and as we've established, DPs really don't want to distress an image that is already distressed by being compressed. If you do work on the image in camera, as the traditional film DP has tended to, then you limit how much data is recorded—you have to work in the colour matrix. If you crush the blacks to get a look you automatically reduce the data that is output into the image display. So current practice is to do very little in camera, so that every bit of data is carried back into post-production, where the work on the image—the grading—can begin. But I contend that when you really look at images produced like this, you'll see a thin patina *over* the image and the 'look' itself is not inherent *within* the image. I've spent thirty years shooting video, as well as film, and I know it's possible to generate the look within the image. It is my contention that simply to light well and to leave everything to post-production is an abrogation of the DPs responsibility as a creative artist. I have many friends in the cinematographic community that now believe this to be true.

Original electronic imaging was analogue in form—as was film—yet the formulation of the capturing of an image was different from film. Film has wide latitude—one can make an intelligent 'mistake' and rework the material and formulate a sense of 'atmosphere' within the image. This is commonly known as 'the look'. Analogue video was clean and clinical, and you had to get the exposure right—in the early days, if you didn't get exposure correct, then you didn't get focus. Colour itself was grafted onto an already set formulation of image capture. I shot one of the first features generated on video and transferred to film for theatrical distribution; this was Birmingham Film and Video Workshop's production *Out of Order* (Jonnie Turpie, Birmingham Film and Video Workshop/Channel 4/BFI, 1987), and I approached the task by imagining video as being like a reversal stock—with very little latitude for mistakes in exposure. Nevertheless, what had I to lose? I tried various colour experiments—for instance, at that time creating a white balance that was off-white was not generally done. I discovered that not only could you tip the white balance towards the corrective areas of colour (blue and orange, cold and warm), you could also tip the balance of colour into any complimentary area—for instance, corrupting the look towards the purple to induce green and any variation to be found around the colour wheel. The transfer to film at that time seemed adequate, but when compared to today's digital transfer techniques, it was not good in terms of colour.

With the advent of Digital Cinematography something very important has happened with image capture. In both photochemical and digital cinematography, until the image is developed, the image resides in latent form in both *the silver halides* and the *un-rendered data.* Development—the bringing forth of an image in film—is similar to the rendering of an image in the electronic domain except for the fact that the materialised film image is negative and in digital cinematography the materialised image is positive. The nature of that difference requires fuller investigation at another time.

For now, it is important to note that, in the latter, colour is within the bit-depth of electronic data and is therefore an integral part of its material form. This developing practical understanding in professional practice is counter to arguments that have circulated previously within media theory. For instance, *New Media: A Critical Introduction* (Lister et al. 2003: 13–21; 35–44) claims there is an essential virtuality to new media, with the immateriality of digital media stressed over and over again. However, industrial and professional expertise now challenges academic convention by seeking to re-inscribe digital image making as a material process. Data labs exist and so one can deduce that data also exists. Large companies like Google and Microsoft position server farms within the arctic circle to take advantage of free cooling – the manipulation of data generates heat. There are various other characteristics to the handling of data that enhance its materiality and evidence is mounting of its materiality as a medium. In a conversation with a colourist in London's Soho, I proposed that the analogy of 'warming the photo-chemical developer, to then change the characteristic response of the film that was going through the developing bath'. Likewise, one might also interfere with the material nature of data within its processes so that the look could be created within the image. This is different from simply 'baking in' a look, which then limits manipulation during post-production. Instead I'm describing the possibility of artistic manipulation within the traditional terms of operation of the cinematographer, rather than limiting the possibilities of others in later processes.

In sum, at the beginning of digital video, when data was generated at low levels via proprietary formats, it was possible to regard its limited presence as being immaterial—now we have to think again. In wanting as much detailed information to be retained as possible, Directors of Photography are expressing the desire for verisimilitude with the real world. This attitude must also prompt the re-investigation of the academic trope of thinking of digital information as being immaterial. Many data labs have now grown up around the world to handle the tsunami of data being generated by the attitude of DPs towards their craft. A major argument for the digital as being material resides in the fact that people are employed in its handling; like any other material, its commodification is a sign of its existence.

The Technological Horizon of the Image

Film was developed with the aid of two seminal technologies preceding it. Like all technologies the first had several inventors engaged in its development: Alexander Parkes investigated Cellulose Nitrate and introduced 'Parksine' in 1861 and later an artificial dental material was introduced by the Albany Dental Plate Company in 1870, invented by John Hyatt. Both lead to Celluloid. The other technology was the introduction of 'intermittent mechanisms' with the first functioning sewing machine in 1830. Barthelemy Thimonnier was nearly lynched by a mob of tailors who saw his invention as something that would lose them work. Nevertheless, together these inventions enabled cinema to come into being.

Early frame rates (12, 14, 16, 18fps) were too slow to generate the sensation of smooth motion, so were then enhanced in the projector by introducing a revolving shutter with 4 sections—two were clear, two were covered—so each frame of film was displayed twice per second. Today we produce 48 (or 72 flashes if there are three open sections) if the film runs at 24 fps. Television emulated this flashing of the image by using interlaced technology that split one frame into two fields. Now with increased computational capability, Digital Cinematography can shoot high frame rates and experiments are underway with viewing images at higher frame rates *and* Higher Dynamic Range.

Film has always had a higher dynamic range than digital video and also digital cinematographic equipment—but this is now changing as DC equipment is now around 10–14 stops of latitude, thus coming close to matching photo-chemical film. But Higher Dynamic Range images are now being produced on still cameras. When the two exposures are combined (captured in two different frames at the same moment), around 18–20 stops of dynamic range are produced. One problem with moving image HDR production is that most systems capture each exposure within the HDR image one after the other. This means that the two different exposures are time-displaced and therefore if there's movement in the frame, blurring occurs which will play hell with Greenscreen. However there are now cameras that capture three exposures at once using a beam splitter.

The other principle issue in HDR research is that all contemporary displays use a mechanism that only displays two to three orders of magnitude. This is currently being dealt with by joining both LED and LCD display processes so that newer HDR exhibition systems will display images that have the same dynamic range as the five instantaneous orders of magnitude of the eye brain system.

The resolution of film is said to be 4k but requires scanning into the digital realm at 6k (so that it has 'headroom'). When you previously saw a film image in a cinema it would often have been at 1k resolution as the processes that have been used to create that image have slowly but surely decreased its resolution (interneg, interpos, release prints, the state of older 35mm projectors etc). Therefore the average image captured digitally and then displayed on a 2k cinema projector is 4 times the resolution of film display. Digital Cinema resolution is increasing month by month, year by year, as regards Moore's Law.

All in all, we are now witnessing a tsunami of development in many different areas with regards to motion imaging. In another example, researchers at the University of Bristol in the Departments of Experimental Psychology and Signal Processing have been conducting experiments to discover differences in immersion between 2D and 3D imaging. These tests have lead to the evaluation of motion stereographic imaging as only having seven per cent more immersive capability than 2D images of the same frame rate and the same resolution. So the project we humans are collectively now formulating is in fact the calibration of motion imaging capture and display, as regards frame rate, dynamic range and resolution so that it hits the 'sweet spot' in human eye/brain physiology. We are now in search of the 'perfect picture'.

One fly in the ointment has been pointed out, albeit mischievously, by Mitch Mitchell (2011: 'Verbatim History'), Head of Imaging and Archive Services at

Technicolor London, who argues with a degree of the pedantry born of innovatory thought, that 24 frames per second is more appropriate than much higher frame rates because it allows time between frames to reflect on the emotional and meaningful elements within the frame, thus enabling the generation of significance and wonder in the human brain. Mitchell's perverse argument is derived from Stephen Poster, the DP who shot *Donnie Darko* (Richard Kelly, USA, 2001). Poster argues that since each frame is being flashed for 50% of the viewing time, in a two-hour film, one hour is effectively spent in the dark—thus allowing for plenty of time to think about what you're watching. The serious point of the joke is that if you increase the frame rate, you won't need to flash into black all the time for physiological reasons, so consequently all reflection time will be lost and the romance of film will die.

Artists and resolution

In my own practice I have often been inspired by the simple act of making work with such wonderful technology. This technology functions faster than the eye or mind. Even analogue video takes one 64 millionth of a second to 'write' a line.

'Duration is to consciousness as light is to the eye' (Bill Viola, quoted in Youngblood 2003). In this statement Viola is proposing that the presence of light is what caused the eye to evolve, and in turn, that consciousness evolved to deal with events that had duration. He is proposing that in a medium where time is an essential factor, waiting reveals so much more.

Viola's roots lie in both the symbolism of Renaissance painting and the Buddhist proposition of Dependant Origination—that everything can only arise in relation to everything else. My own roots grew out of the moment that I realized that all things record an image through duration: from a lowly rock which, if left shadowed long enough, records the shadow of an image; to paper that has a leaf left on it in bright sunlight; to celluloid that holds a coating; to tubes, chips and sensors that react to light.

Early Days

My first encounter with videotape was in 1976 with 2-inch analogue quadruplex. One took a razor blade and cut it, just like film, then spliced it together to make an edit. Then re-recording came along, and we set up machines to record the next bit of video in line—thus creating an edit and also consequently, image deterioration.

Around 1982 I was managing a video facility in Soho called Videomakers. The owner of the studio was the son of an electronics inventor and watched while we tried to accomplish a simple dissolve between one image to another for a piece of work I was making. Unable to contain his excitement, he told us that his father had successfully harnessed a computer to 'revolve' a still image. He explained that with a little bit of development the image could be refreshed twelve times per second—so, by doubling and then interlacing, by splitting the image into odd and even lines, a whole second of video and henceforth a moving TV image could be revolved. In this case, through a sole inventor and not a corporation, we groped our way through the late analogue age and into the early neo-digital. Our main concern was how to adjust our thinking processes to cope with the new paradigm: to the fact that with a digital event, one had something that could be infinitely manipulated. One could therefore systematize the process—thus giving rise to 'the operations' as Lev Manovich (2002) has termed them.

Every video artist has enjoyed the accidents that have come about through stressing the parameters of low definition equipment. However, Digital Cinematography offers a different kind of unveiling of form. The major difference is that image capture can be achieved without *necessarily* stressing the media. This then prompts questions about the aesthetics of Digital Cinematography. Given that a primary ingredient of the artist's palette is to find surprises within the medium itself, what new strategies can the artist or practitioner use to unveil a deeper insight into content? Though McLuhan tells us this should not be so, could the message Digital Cinematography delivers be the beginnings of transparency?

To return to Viola: 'Duration is to consciousness as light is to the eye.' But High Definition can deliver not just duration, but articulation. So we might now remember how increased resolutions could affect how and what we see and therefore reformulate his observation like this: 'Definition is to consciousness—as luminosity is to the eye.'

Art and compression

In 1987, John Wyver carried Walter Benjamin's 1936 ideas forward, with the help of Jean Baudrillard and Paul Virilio, in his programme *L'objet d'art a l'age electronique*, broadcast on the satellite station La Sept. He asked: 'Can a reproduction carry any of the authenticity of the original?'. At that time the world was concerned with analogue representations, which decay in their passage from copy to copy, from medium to medium. If one proceeded with digital compression using Fourier's earlier mathematics, then Benjamin's question might unveil a buried insight: *To copy is to decrease.* With digital copying this might still ring true—not only because things are changed and lessened in the act of copying—but because there is a sense in which the representation itself is simply a 'Borg', a copy without feeling, without the 'true' sense of the original.

Over twenty years later, the spirit of the question still stands. Where is meaning, significance and value in the digital domain, given that the medium of reproduction and the medium of origination reside together in the same realm? Has the idea that things can be 'derivative' become defunct? Is not everything both derivative and original at the same time? Is the idea of the 'original' now anachronistic?

Technologies, Aesthetics and Art Converging

As there is a blurring of the lines between form and content, so there is also a blurring of the lines between software, hardware and that nether region of firmware, which tells hardware to *be* something—rather than *do* something. Now, through this blurring, and through a combination of the use of the web and digital media, a new kind of aesthetic is becoming available, in what has been termed convergence. Herman Hesse predicted post-modernism and its bastard digital child 'Convergence' in his 1943 work *The Glass Bead Game*. In the game itself, one might take a bar of Mozart and place it next to a brushstroke by Matisse, a line of poetry by Omar Khayyám and a silk screen by Warhol and so create a new work of art. Here, derivation is all; in fact it has been canonized. Hesse proposes the notion that authenticity is not only present in the copy but that the two are one and the same—that the artwork's weight accumulates with the weight of the addition of other copies and their imbued authenticity and all combine together into new, authentic works of art. In pursuit of such an *aesthetic conglomerate*, the actions of the new technologies *and the way the technology is being innovated* has itself become a developing aesthetic.

Resolution/Revolution

To return to where I began, on 31 August 2007, when Jim Jannard and Red delivered their first complement of twenty-five Red cameras to a selected few, they set the world alight with their offer of cheap and high level wavelet technology (and made it available faster than any previous technological advance of this order). The introduction of 4k was a moment of industrial re-organization. This new technology allowed people who previously would not have had the opportunity to enter into the industry. This resulted in a shift in the industrial hierarchy, one that is part of a cyclical phenomenon that comes in waves about every five years. Overtly it looks like a change in technology; covertly it's also a change in employment functions.

In parallel to such events, there is the ongoing development of User Generated Technology, coming out of an individualist trend that has somehow remained alive through late capitalism. For example, in the early 2000s Jeff Krienes, a Director of Photography in California, was experimenting with a friend from Thomson Grass Valley on a prototype HD Camera. They had become fed up with the slowing of technical innovation emerging from the big corporations; so they tried to create a camera that fulfilled not only their needs, but also their aspirations. They made an aluminium case that contained some electronics and a few chips, had a fitting on the front to take a 35mm lens and, on top, the stripped down carcasses of twenty early iPods to RAID record the high data output. This camera had nearly the same specifications of the Red Camera. Though Red may look like the trailblazers, they are in fact the inheritors of a User-Generated, YouTube-like attitude to the production of technology.

In sum, in contrast to the early sole inventors in Fourier's time, it may appear that we have just been through a long period where corporations, from the late analogue to the current digital cinematographic age have controlled the means of innovation. Yet as the digital reveals its nature it would seem that there is indeed open access to high-level technical innovation *for the individual*. There are recent incidents of companies with only one or two employees (such as the Digital Bolex company, which produces a 2k camera, which has already been brought to market). This apparent individual engagement with technology is a hallmark of our era, and this trend is currently centring on the production of High Definition or Digital Cinematographic technology.

The commonality of information available through the web is also allowing a commonality of aspiration so that the User, and now the Doer, is also the Maker and the Knower of their own world. As we make the transition between old and new states, a fluttering is occurring, a switching between the two states in the suspension of our disbelief. Through these changes, the definition of the self is expanding—the idea of what an individual is being re-defined as it is being up-rezzed to a higher level of definition.

Postscript

Though this chapter has its own specificities, it should be read within the growing understanding of what the digital realm is becoming. This can be aided by viewing a series of online interviews entitled 'A Verbatim History of the Aesthetics, Technology and Techniques of Digital Cinematography', which can be found at: www.visualfields.co.uk/indexHDresource.htm

Film history between 1890 and 1915 is fairly devoid of verbatim reports from the practitioners and designers of the medium. It seemed to me that the development of HD would occur in a mirror period 100 years later between 1990 and 2015 and I wanted to make sure that this absence of original voices did not happen again. This resulted in the 'Verbatim History' project that was part funded by an AHRC Knowledge Transfer Fellowship, and also supported by the University of Bristol, Arts Council England, Watershed Arts Centre and South West Screen.

Whilst making this ongoing resource I have become aware of various disabling predilections within current digital thinking. For instance: ideas around convergent and pervasive media have been developed with a low resolution approach to the world partially due to the available technology which placed a lower demand on the computational resources that were available. Of course higher resolutions demand higher processing and rendering levels, and in the beginning people were more interested in enabling the idea of pervasive media to function to be too worried about the level at which it worked.

Like notions of remediation within incoming media that seek to describe these changes in terms of the medium that is already existent, early forms of technology within a medium are less efficient and less powerful than later versions and therefore aspiration tends toward lower expectations. Yet upon looking deeper at the notion of the convergent, one can see that it points toward a time when higher resolutions will be required—to a time where the idea of the *convergent* will be replaced by the *integrative*. If you are living within a world where gesture can stimulate digital events you will want to make a small gesture with a hand rather than expend energy on waving your whole arm around. This is simply a question of resolution, and that in turn is a question of processing, compression and latency.

The 'Verbatim History', though ostensibly concerned with ideas of image resolution, is actually about the development of the digital domain in general through the viewpoint of motion image creation.

Current Research (2014)

At University of the West of England, the center for Centre for Moving Image Research (C M I R) will be examining developments in moving image technologies. My own current research strategy now centres on human physiological specificity and I've been working, in collaboration with University of Bristol and BBC Research and Development, on extending my earlier investigation into the immersive qualities of the image through increases of resolution, by combining the properties of higher frame rate, higher resolution and higher dynamic range images. In November 2012 we completed the first ever test shoot for this level of motion image production at 50 and 200 frames per second—the latest capture project took place in Bristol in April 2013, the results of which were published in a BBC White Paper at IBC in September 2013 entitled 'The Production of High Dynamic Range Video', by Marc Price, David Bull, Terry Flaxton, Stephen Hinde, Richard Salmon, Alia Sheikh, Graham Thomas and Aaron Zhang.

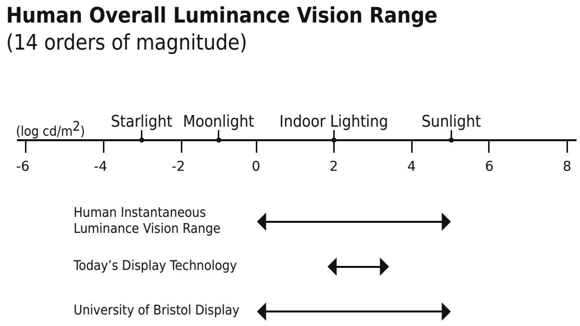

Figure 1. Human Overall Luminance Vision Range.

If you look at figure 1 it shows that the human eye/brain pathway uses 5 out of a 14 order of magnitude scale, sliding this instantaneous facility up and down the scale to deal with starlight at one end and desert sun at the other. All contemporary displays only currently show between 2–3 orders of this scale, but we now have a new prototype which displays across 5 orders and the BBC in turn have created a 200 frame per second projection system. By combining variants of frame rate, resolution and dynamic range, we should be able to effectively produce 'the perfect picture' by then calibrating these functions to produce a combination that best resonates with our eye/brain pathway—and therefore conscious awareness. The proposition is that if we can manipulate *all* the factors of the construction of the digital image then conscious immersion may follow.

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