

Light and Colour in the Digital Domain

Sean Cubitt

Paper presented to the Digital Aesthetics 2 conference,
University of Central Lancashire, Preston, March 17 2007

The human eye can only see so much. At the infrared and ultraviolet margins of the visible spectrum, we are sensitive to wavelengths just at the edge of vision, but only if they are much more energetic than is the case with light closer to the centre of the visible range. Individual sensitivity varies too, and varies over time. Manufacturers have to take that into account as they work out what colours to make available on screens. The typical colour gamut (the range of colours made available on a CRT [cathode ray tube] or LCD [liquid crystal display] screen) shrinks away from those difficult-to-see edge conditions, not least because they require more energy to make them visible at all.

As is so often the case, the solution creates a new problem. Without those limit instances of visibility, the other colours that are retained in the gamut lose some of the clarity of their contrasts. The solution is to use an algorithm to resituate each colour in relation to the others. A standard CRT Because a lesser total area of the spectrum is available, the colours that we can reproduce usefully need to be spaced out differently, to retain as well as possible their distinctions from one another.

Which leads to a second problem. Each manufacturer tends to work with a different algorithm, giving us the familiar problem of graphics that look fine on Windows looking muddy on Mac OS or Linux, and vice versa. The effect is even more visible if you see a film in the cinema and then on a computer screen: photographic film has a much wider gamut than electronic screens, and transfers to DVD end up dimmer and with less defined distinctions between tones.

The Commission Internationale sur l'Eclairage (CIE) in 1931 developed a spatialised model of the visible spectrum based on experiments conducted in the late 1920s

on human optics. Our eyes register three orders of short, medium and long wavelengths, corresponding to blue, green and red colour experiences. Any colour we can perceive is a combination of these three. The CIE diagram uses three values, X,Y and Z corresponding to the three optical primaries, which gives a three dimensional space. Projected onto two dimensions, we get the familiar horseshoe-shaped diagram. Typically, a CRT or digital projection system will offer colour within a strictly limited triangular region within the CIE colour space.

Our technologies are not the same as eyes. The colours they refer to aren't those that the retinal cones receive (the 'red' cone is closer to orange; and overlaps with the 'green' cone's wavelengths). And there is a problem in focusing on all three colour zones simultaneously which evidences the brain interpolating data in the perception process. The algorithms used to correct the inefficiencies of screen gamuts could be made out to be analogous to this 'intelligent' interpolation, but that seems to be pushing the definition of intelligence way beyond what it normally has to bear.

The manipulation of pigments has always posed challenges too. Earth colours have been relatively easy to derive from chalks and clays, even though many of them have been and remain sacred. Other pigments derive from rare minerals, very local animals, or difficult, time-consuming processes: Afghani lapis lazuli pounded to make aquamarine; the tears of the Tyrean *murex* sea-snail for imperial purple; the stamens of croci to make saffron yellow. Their handling tied to ancient guilds, such colours exchanged their sacred status for sheer expense. The traditional blue robes of Mary the Mother of God were blue because it was the most expensive colour of all. Michelangelo's unfinished *Entombment* of 1501, now in the National Gallery in London, is unfinished, it is believed, because he died waiting for a shipment of pigment from the Hindu Kush.

The invention of aniline dyes based on coal tar in March of 1856 by the 18-year-old William Henry Perkin of Shadwell changed much of that, powering the mid-Victorian craze for mauve. Aniline dyes are at the heart of the brilliance of moder-

nity, despite their curious overlap with what fashion historians call 'the great masculine renunciation', the turn of male clothing away from splendid tights, cod-pieces and jewelled lace to the drab uniform of the business suit. The possibilities for clothing, interior and exterior decorating, art (think of the pre-Raphaelites) and ultimately photography exploded. Digital colour is a long way from the brilliance of the artificial real.

One way around the problem is suggested in the art of Cézanne and Seurat, both of whom devoted themselves to using the combination of colours to produce optical effects, in particular in search of a way to reproduce, with pigments, the effects of light. Light is of course very different to pigment. A pigment absorbs all light except the colour we see: black pigment absorbs pretty much everything; white reflects pretty much everything; blue absorbs red and green wavelengths and reflects what's left. No matter how brilliant, pigments will tend to absorb light, and therefore to dim the quantity of light they return to the eye. In principle screens that act as light sources should be able to generate more light than that. Oddly, it is reflected light, in the form of cinema projection, that offers some of our most startlingly brilliant light effects, while digital screens and, so far, digital projection have trouble matching the range of colours, if not necessarily the levels of luminance.

At the risk of telling half my audience what they already know, and baffling the other half with unwonted (and unwanted) technicalities, this little preamble seems necessary. Some years I taught on the Summer School for the Open University's Modern Art course. Part of our job was to take students round the London galleries. I worked on a module on 'Art and Society', and as one of the exercisees, I asked students to engage with other, non-University discourses in the galleries: children's tours, tile cards, and lunchtime lectures. Among the many I attended, one in particular sticks in memory: a slightly irascible Courtauld graduate addressing a motley crew of random visitors on the techniques employed by Constable in one of his early works. I was fascinated. Coming from the Screen school of film theory, I was full of Marx, lacan and Saussure but, I realised, I knew nothing at all about the ma-

terial of cinema. At the time I worked in the Rio Cinema, in Dalston, and was training as a projectionist, so I had at least some awareness of the physical nature of the medium. Eventually, all projectionists end up with sciatica from toting those great cans of film up above the highest seats; but before they do, they have to check every sprocket hole prior to mounting on the projector. I knew enough to tell a good print from a bad one, a good splice from a bad, but I hadn't, and to some extent still don't have, much idea about film stocks, or lenses, or lighting.

The field of media studies is curiously ignorant of its material basis; and it seems as if art history is moving in a similar direction. Perhaps both of us are following the model of English Literature, which rarely seems to look at books, isolating instead an ineffable essence of text that floats apart from inks, paper, fonts and book design. What I have come to say is that this is a very poor place to be; and that the study of digital light is, for me, and in all humility, an effort to redress the balance of what I now feel to be an act of abandonment, a lapse from the foundations of scholarship which otherwise I profess to uphold, especially as I try to present myself as a materialist.

There is a peculiar timeliness about this project. In 2005, Adobe amalgamated with Macromedia. The expectation throughout the image-processing and desktop publishing world is that the CS and MX units of the two firms will be integrated into an unstoppably good collection of 2D design tools, powered by Adobe's remarkable workflow manager. The same year saw the takeover of Alias by Autodesk. The names may be less familiar, unless you're in 3D. Autodesk have a commanding position in the computer-aided design and manufacture market with a suite of software products, notably AutoCAD, with over 7.5 million seats worldwide. The Alias acquisition brought them Maya, one of the handful of contenders for top 3D animation tool, to add to Max, which they already owned. Also in their suite, the Montreal-based company Discreet, whose, Smoke, Flame, Inferno and other compositing and cleaning packages are industry leaders in media and entertainment. The 3D world has long been a tricky one: there are several competing end-user packages, each of them pretty expensive. Art and design schools can't afford

to buy licenses for them all. The Autodesk acquisition may well bring us an overall winner. Their recently announced Toxic workflow manager may be the killer app that integrates the suite and makes it easier to use the raft of expertise, rather than try to get disparate programs to talk to each other, which remains the bane of Linux-based freeware apps.

These backroom economics have potentially significant effects on the way digital light is handled. The market position of Adobe, and the potential position of Autodesk, are such that their ways of doing things are likely to create, for a generation, *the way of doing things*. I am not, today at any rate, especially worried about the potential for market monopoly. Nor do I have special bones to pick with either company's products. I am not even all that worried about proprietary algorithms, and the fate of alternate open source freeware like Gimp and Blender. What concerns me is the possibility that the protocols developed by these two firms will become the *de facto* norms of digital light and colour.

Every technology has what engineers call its affordances, its capabilities and limitations. A bicycle has, de Landa tells me, ten degrees of freedom, based on the number of its moving parts. Alongside aniline dyes and the photographic media perhaps the greatest achievement of the 19th century, the A-frame bike made freedom possible for working women as well as men; it opened up the countryside to factory labourers and to that extent enabled the first inklings of environmental politics. But it can only do so much. It is certainly less speedy than a car. Except of course, that it is far less vulnerable to traffic jams. Indeed by the time I left London in 1989, the average speed of cyclists already outstripped that of private motorists in the inner city. The affordances, in other words, include both integral capacities and constraints, and extrinsic ones, such as the impact of multiplying the number of private cars on overburdened road systems.

Likewise the affordances of software products. Every new advance – Weta's subcutaneous reflections on Gollum's skin in the third *Lord of the Rings* movie, Rhythm 'n' Hues algorithm for Aslan's fur in *The Lion, The Witch and the Wardrobe*, Pixar's dust

in *Cars* – has us reaching for superlatives. A special effect, after all, is only special to the extent that it attracts the epithet 'cutting edge'. But for most of us, and for most of the industry, light effects and their corollary technical processes are more bread and butter than that. Phong shading, which seemed to open so many avenues when Bui Tuong Phong published the algorithms in his 1973 Ph.D, is now a standard tool in any vector program. The soft objects and z-buffers that were once the Holy Grails of developers are now second nature to a generation weaned on them, so deeply have they entered the toolbox or, as the poet John Montague has it, so deeply has the harness worn in.

3D light is, as Cathryn Vasseleou notes, in principle no different to electric light in the degree of its artifice. For millenia, humans had only sunlight or fire to illuminate the world, and starlight to engage and perhaps inaugurate the virtue of wonder. In the 19th century, first gas and then electric illumination rattled the cage doors, variously enchanting the world or, as Schivelbusch would have it, disenchanting the night (and protests against light pollution in recent decades would bear him out). The physics engines of games software emulate gravity: why should 3D programs not emulate the physics of light? I give one small example: digital fog. Though there are interesting experiments in the optical simulation of clouds, fog is a rather different process, the automatic populating of virtual 3D spaces with an algorithm that emulates the scattering of light in the atmosphere to which we owe the bluing of distant horizons. The term fog is evocative, not only because it takes account of and to that extent visualises distance by filling it with mathematical behaviours. It is also evocative in calling up images of meteorological conditions, parameters based on the observation that the higher the humidity, the greater the effect of scattering. The difference is of course that, in a way that all but defines the uncontrollable, we have no powers over weather. Real world fog, moreover, is lumpy, denser here than there, and capable of quite extraordinary effects which virtual space would be at pains to emulate. I think of mornings on the Mersey ferry when the fogbanks reduced lateral visibility to a matter of feet, while overhead brilliant sunshine might illuminate the towers of the Liver Building. This is not a matter of mathematicisatin being bad: should anyone want it, I imagine writing the code

for clumping fog would be quite feasible, if indeed it hasn't already been done. One of my favourite of all natural effects of light, the glory witnessed occasionally on early morning mountain hikes when you rise above the clouds and cast a rainbow-hemmed shadow on them. It seems easy enough to imagine the algorithms for that to be made available, just as the glory itself, once the province of adventurers and pastoralists, has been democratised by air travel. However abstract it is capable of becoming, maths will never shake off its role as a key instrument in describing the world, even if we can no longer share the Pythagorean belief in the absolute immanence of number in the effects of nature. For me the question is not about what our machines and invention are capable of, but of the normalising of standard practices and techniques, our ability to settle for the good enough.

A case that I find especially fascinating is that of water. While other effects have stolen the limelight in the history of visual communication – the inability of people far more familiar than ourselves with livestock to agree on whether all four of a horse's hooves are ever simultaneously off the ground at the gallop, for instance – water has a special place in that chronology. Leonardo's 1508-9 *Study of Water Falling Into Still Water* is an extraordinary attempt to capture an x-ray of turbulence before either idea had been formulated. Whether these were studies for the sheer art of it, or preliminary sketches to his waterwheels and locks, the intelligence and acuity of vision is to this day remarkable. And yet we scarcely recognise the water he depicts. Leonardo plies his pencil in practiced arabesques that recall sketches of hair, and though he catches the foaming bubbles, he is constrained by the pictorial language of his time to draw his eddies as braided lines, lines that stand in at once for edges and for trajectories (like speed lines in reverse), and in the shaded area towards the centre left, as simple hatching to denote a deeper colour under the shadow of the turbulent surface.

But how exactly is digital water any more or less strange, any more or less accountable to the habitual modes of visualisation we employ? NASA telemetry from the Mars Rover includes some stunning images from which areologists derive con-

ceptual evidence for the historical presence of water on the planet's surface. An image from the 24th of October 2002 shows a cliff standing out from the sand or dust, highlit by a lateral blast of sunlight, with a channel running down from a dark patch near the top and centre of the frame with every characteristic of a dry gully. Needless to say, whether this is a hydraulic or geological phenomenon is hotly debated. What concerns me more is the way in which the image presents itself to us as an artefact: as a photograph.

We have certain expectations of photography, despite all our semiotic awareness. This image is not a photograph, although it looks like one. It is a digital image captured in a number of wavelengths, not all of them visible to the human eye, transmitted digitally to earth and reassembled in visible wavelengths. The high sheen apparent at the upper edges of the frame recalls some of Ansel Adams' prints in its approximation of the American Transcendentalist appreciation of landscape. That these are artefactual (that is, accidents of the procedures used to create the image) is apparent from a closer view of the same area; yet the quality of light that we perceive, in this case very much digital light, is allied as much to the tradition of the fine art print as to the requirements of scientific investigation. The visible elements of the image lie on top of non-visible elements which, for example by recording the infra-red signatures of the rocks, can indicate heat-retention and thereby clues to the chemical composition of the landscape. The more obvious false-colour images used in earth observation by satellite, the ones where red stands in for foliage for example, are only more obviously both digital and scientifically legible. This image of the Mars gullies, while it recalls terrestrial landscapes, also startles by the alien mystique we derive from knowing about its generation.

In February 2007, scientists using the Spitzer Infra-red space observatory (the fourth and last of NASA's four 'Great Observatories' which include Hubble, the Chandra X-Ray and the Compton gamma-ray satellites) managed to capture spectrometry from two extra-solar planets, almost certainly gas giants, respectively 62 and 153 light-years from Earth. Only partial spectra can be obtained, unsurprisingly given the distances, by gathering one measurement when the planet is visible from Earth

and another when it is eclipsed by its parent star, assessing the difference between the spectral results in each instance. That like its sister platforms, Spitzer operates for the most part in invisible regions of the electro-magnetic spectrum is only part of the problem, which Carl Grillmair of the Spitzer Science Center described as 'like trying to see a firefly next to an airport searchlight from several miles away' (Alexander 2007). Nor is it simply that the legible spectrum obtained was remarkably flat, suggesting that the planets are unusually dark, perhaps from the presence of silicates whose presence is being inferred from the available data. A parallel case arose with the Hubble Space Telescope's photon counter, a camera which gathers individual photons that have travelled across deep space from the furthest reaches of the universe. In one visualisation process, the data assembled from the smearing of the photons which results from their millennial journey and from the precise angle of their trajectories is presented in image form. Strictly speaking, although the original photosensitive event is entirely analogous to both photographic and biological optics – the conversion of a quantum of light into an electro-chemical event – such presentations should properly be understood as visualisations, as artificial as, say, the graphical presentation of earth tremors produced by seismographs. Like the telemetry from the outer solar system presented in *radioquaglia's radio astronomy* (<http://www.radioquaglia.net/>), rendering alien data in humanly perceptible form is both as scientific tool and an instrument of wonder.

It is in this sense of visualisation that we should approach such tools as Photoshop's Render filters, like Lens Flare and Lighting Effects, or 3D lighting, or indeed the imagination of water that Leonardo brought to light. Although the Impressionists, especially Renoir but also Manet, Pissarro and Monet, brought some marvellous effects into the visual armoury, they seem always to have devoted themselves to calm circumstances. Perhaps because of the *plein air* tradition, which rather encourages working in clement weather, the Impressionists devoted themselves to still waters, and to the predominantly surface effects consequent on this choice. For the now unfashionable genre painters of the 17th, 18th and 19th centuries, from Ludolf Backhuysen to Clarkson Stanfield, water was the dramatic foil to warfare, shipwreck and terror. Where the Impressionists would see the boundary of the hu-

man world as a distorting mirror, a threshold equivalent to all those paintings of light industrial buildings and streets at the edge of towns and cities. For Impressionism, nature wanders into the city like a garden, and theirs is, in no pejorative sense, a suburban art. Backhuysen's 1667 *Ships in Distress off a Rocky Coast* or Stanfield's *On the Dogger Bank* of 1846 deal with quite different subjects: the high drama of merchantmen storm-driven towards the rocks, and a frighteningly buoyant trawler tossed on the surges of the North Sea fishing grounds under the towering skies of Dutch landscape painting of a century earlier. But both have committed themselves to capturing not only the surface but the depth of water, Where Renoir's view of La Grenouillère shows deft use of wet-on-wet handling of the paint, both Backhuysen and Stanfield have clearly built their water layer upon layer, from the underpainting – pinker for Backhuysen, lemony-white for Stanfield – to the final varnish.

Both moods of water pose stiff challenges to digital designers. Water is not scalable: it acts quite differently if we are dealing with a bucket or a bay. While Stanfield did do some experiments with spray, they are not frequent or particularly convincing: the glassy surfaces of his *Dogger* painting are more typical. Spray raises all the absurdly difficult issues of internal reflection common to all water, but to the power of ten. Backhuysen settles for a generic turbulence, and both rely on the translucence of each succeeding layer to produce the effects of internal reflection.

Compare these with the efforts of digital special effects houses in the feature film market. Wolfgang Peteren's *The Perfect Storm* was compelling enough at its first release, using photography of real water and spray from immense dump tanks over the trawler tank set and the ambient darkness of the storm to mask weaknesses in the realisation of the monster waves called for by the script (and the events it was based on). The behaviour of large masses of water is precarious, liable to break up into foam, that is to combine the behaviour of huge volumes with that of the near-molecular scale of spray.

Kac and transmitted light

REFERENCES

Alexander, Amir (2007), 'Spitzer Captures the Light from Dry Distant Worlds' The Planetary Society, Planetary News: Extrasolar Planets, 21 February, http://www.planetary.org/news/2007/0221_Spitzer_Captures_the_Light_from_Dry.html