Enumerating Photography from Spot Meter to CCD
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Abstract
The transition form analogue to digital photography was not accomplished in a single step. It required a number of feeder technologies which enabled and structured the nature of digital photography. Among those traced in this article, the most important is the genesis of the raster grid, which is now hard-wired into the design of the most widely employed photographic chip, the charge-couple device (CCD). In tracing this history from origins in half-tone printing, the authors argue that qualities available to analogue photographers are no longer available to digital, and that these changes correspond to historical developments in the wider political and economic world. They conclude, however, that these losses may yet be turned into gains.

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When, in 1835, William Henry Fox Talbot exposed a plate illuminated by the light falling through the latticed window of his home at Lacock Abbey, it is unlikely he considered that his image might appear to observers a hundred and seventy-five years later as a precursor to the most familiar geometry of modernity: the grid. From a subject for photography to the very principle of its operation, the grid has expanded from map projections, urban planning, and mathematical exercise books to become both an aesthetic icon and a guiding principle in the construction of cameras and printers. Such continuities between past and present technologies belie the apparent rift between traditional and digital photography. Curiously, certain practices in traditional fine art photography, ostensibly incompatible with digital technology, can also be understood as contributing to the mathematicisation of the image and the institutionalisation of the raster grid that are such central hallmarks of digital photography. Our concern in this paper is to emphasise the origins of the discrete, automated and arithmetic logic of contemporary digital imaging in the longer history of photography. To do so, we take three exemplary instances: the unique account of technical practice left by the North American photographer Ansel Adams; the history of half-tone printing, which in many sense links the analogue and digital phases of photography through the introduction of electronics and the clock function; and the design of the CCD (charge coupled device) chip used extensively in digital cameras.

Adams and Abstraction

Our essay focuses on the quality of photographic texture which, in traditional, chemical photography, is a compromise between contrast and grain; that is, the density of silver in a print. The two qualities that together form the sense of texture are resolution (the number of grains per square inch or centimetre) and acutance (the clarity of edges). Many qualities of the medium act against such clarity. The 'circle of confusion', that is the circle of light which surrounds any exposed point on the negative, is a finite quantity that can be reduced, but never to zero.[i] Halation, the effect of light passing through the film strip and reflecting back onto the light-sensitive emulsion, causes haloes around bright points (Adams 1995b: 17), while the unavoidable spontaneous reduction of trace molecules of silver halide produce ‘chemical fog' (Adams 1995b: 87) which degrades the shadows of the negative and highlights of the print. While photography is today commonly discussed in terms of image capture and distribution, it has also, centrally, been a print medium. ‘For example,’ wrote Ansel Adams in *The Print*:

> I have found that Seagull Grade 4 gives me a better print of my *Frozen Lake and Cliffs* than I was ever able to get on Agfa Brovira Grade 6, and the tone is magnificent. This is one of those significant early negatives (c. 1932) that must be considered quite poor in quality and *very* difficult to print. The negative contains enough information to yield an acceptable print with great effort, and I continue to improve the 'salvage' printing as best I can (Adams 1983: 50).

What is so amazing about this 25-year struggle to find an 'acceptable' realisation of an image is not just the sheer level of work involved, but the way Adams sets his visualisation against that realisation, a constant theme in his three great books on photographic technique. When students are introduced to the basics of technical photographic theory, this is what they find: physics, optics and chemistry (or electronic processes in the case of digital photography): theory whose central task is to make it possible to produce new work, or in this case to remake old work in pursuit of a new outcome. In separating the conception of the image (whatever coerced him to make the image in the first place) from the means of production, Adams demonstrates a powerfully moral sensibility. His assessment of the negative is pitiless (regardless of an attachment that has him reprinting it quarter of a century later, it 'must be considered as of poor quality'). But even to Adams, the quintessential technologist, the means of production was only a means to a desired end – the print.

When he was working with Lakeside Press in Chicago on the then new process of photomechanical transfer, Adams reported that they were 'pleased beyond words to have the chance to find out the procedure on such work' (Hammond 2002: 50). This is the same man who, in his *Autobiography*, would say 'I believe in beauty. I believe in stones and water, air and soil, people and their future and fate' (Hammond 2002: 50). As a pioneering environmentalist, Adams was devoted to nature and to the scientific knowledge of nature; as a technologist he was an assured manipulator of the laws of nature; and in his ethical responsibility to both the Yosemite and his own negatives and prints, these convictions were united in a single creative practice.

We have to imagine him in the darkroom working the negative in order to produce a rememoration of the landscape, not only as raw experience but as an experience framed in the knowledge that, for example, Yosemite was already a threatened wilderness (whence the centrality of his photography to the project of the Sierra Club). As printmaker, Adams' commitment to the darkroom was an attempt to establish artisan credentials for photography generally and for his prints in particular, as opposed, for example, to the seized moments of life on the wing in Henri Cartier-Bresson's photography. If anything is, Adams' are graven images. In his nostalgia, Adams is working not only with a memory but with an expectation – whence the many prints of *Cliff with Frozen Lake*. The work he undertakes in the darkroom is *precise*: etymologically it 'cuts before'. His fieldwork is undertaken in the expectation of finding the landscape that is already there in the imagination; his darkroom practice not only restores the vision (and the visions of precursors) he brought as expectation to the landscape – it is itself a pre-vision of the prints which as yet do not exist. So the prints encapsulate excision, incision and precision. Their stilling involves not only the cutting out of the moment from the rest of time but all these past and future orientations. In this sense they are not present at all. They arrest vanishing and becoming not only of the landscapes and their changing light but the vanishing and becoming of the photographer, his experiences, even his darkroom.

Contra the idea that technology is a barrier to experience, Adams' work seems to suggest that while his craft is conscious, it is also a dialogue, not only with the natural green world and the laws of physics, but with apparatuses he is not in any simple way constrained to employ. Craft is conscious because it is a dialogue, because it necessitates an intrigue of three partners, physics, technology and the artist. Of the three, the least conscious, in this instance at least, is the artist, not because he is operating on automatic, not at all – on the contrary. But if we are right to say that artists, like anyone else, are social constructs, what is unconscious in the artist is the society that constructs him. Looking at the prints, or considering the accounts he gives of their making, it is hard to see Adams as the kind of technologist who devotes himself to overcoming either the tools or the objects of his art. Sure, he is happy enough to arm-wrestle light till it gives him the heightened responses he dreams of; and sure enough he is happy to innovate in his technological practice to get the finest result the engines he has at his disposal will come up with. What he does not seem to want is to win, to subdue the light of the world or the properties of his materials and his kit. If anything, he expresses a desire to submit to them.

But this submission is not about submission to the values of reality, where the word 'values' has the very specific meaning it has in photometry as a measure of brightness. Greyscale photography has only brightness, 'value', to display. Certainly hues are significant too: various film stocks are more or less sensitive to specific wavelengths, and skilled photographers and cinematographers used colour filters to enhance skies, foliage and faces long before the industrialisation of colour film. Likewise, various papers fundamentally alter print colour, determining warmer and cooler tones. Adams was heavily influenced by Pictorialism early in his career – a movement that largely subscribed to the idea that art photography needed to emulate the painting and etching of the time, through techniques such as soft focus, special filters, lens coatings and exotic printing processes in the darkroom. Adams retains a pictorialist ethos insofar as he is adamant that he does not aim to reproduce the scene as it appears to ordinary human vision. As a modernist, overwhelmingly concerned with the form of the image, its transformation by a singular artistic vision, he approves of the upside-down image on the ground glass on the back of the large-format view camera because it abstracts the values on the plate from the scene they otherwise represent (Adams 1995a: 30). As a teacher, he recommends various techniques for abstraction, from looking through a monochromatic viewing filter to isolating elements of a scene by looking through a cardboard mailing tube, or using a spot meter to register the brightness of small areas within the scene.[ii] The entire principle of the Zone System, which he elaborates in *The Negative* – probably the defining technical manual of photography – is to differentiate and abstract the photographer's visualisation from the subject that lies in front of the camera. It is not simply that the photograph is greyscale and two dimensional, but that the values (the brightnesses) of individual areas in the frame are there to be used. If the photographer opts to expose his film in such a way that a sheet of white paper appears as middle-grey, and if in the process reveals details in shadows or in highlights that might otherwise be lost, or alters the balance between sky and cloud, or renders autumn foliage as dramatic highlights where naturally it would produce a dull grey, so be it. The vision, the ‘previsualisation’ which precedes and guides the entire process – from choosing a lens to framing a print – is about that finished object, not the imaged scene, even though Adams' fine print tradition concentrates on already photogenic subjects such as desert landscapes, weathered walls and rocks.; or if it is about the scene, it is about some truth about the scene, emotional or intellectual, not about how it looked to the photographer when the shutter opened. In this sense previsualisation generalises Alfred Stieglitz’s notion of the 'equivalent', whereby subjects such as clouds 'stand-in' for something spiritual; that is, the refined beauty of the print transcends its subject (Norman 1973). In this sense, we can understand Adams practice and his technical manuals as guides to understanding photography as abstraction of vision from the merely seen.

Photometry and the Control of Light

Texture in photography is the product of illumination, distance to the subject, focal length, aperture, exposure time, efficiency of the lens (multi-component lenses, even coated, lose light by reflection, Ansel Adams, 1995a, 133 and passim); of film speed, the type of developer used, duration, temperature and agitation of the development process, the type and duration of fixing and the care taken in washing and drying the negative (Adams 1995b, 29ff, 181) and in printing the quality of the materials and paper used, the duration of exposure for various areas of the negative, and the final viewing conditions of the print.[iii] In Adams’ trilogy of technical manuals, each of these processes is open to intervention by ‘the creative photographer’, while at the same time he argues that obsession with technical prowess cannot substitute for an intuitive grasp of each of these variables – plus lights, flash, colour temperatures and so on. In other words, the richness of photography is that it is irreducible, in Adams' world, to *automation*. The photographer is quite capable of enjoying a schoolmasterly arithmetic exposition of the inverse square rule in foot-candles, but equally seems quite happy that manufacturers of light meters fail to agree on a common standard. It allows him to replace their proprietary scales with his own, the Zone System: to turn nascent automation of exposure readings into a creative practice of their own with the addition of an adhesive tape with handwritten numerals on it. It is the archetypal jury-rigged solution to a partially effective piece of kit.[iv]

Neither the original Weston light meter nor the more sophisticated SEI (Salford Electrical Instruments) Photometer provided any level of automation. They simply provided ‘objective measurements’, that needed to be interpreted, and each film manufacturer had their own system for interpreting relative film speed and consequently the exposure value. Therefore applying a zone scale over the top, effectively renaming the manufacturer's scale, was about a different interpretation of what was measured, what it meant, and what you could do, or wanted to do, with that data. This challenge continues today, where a photographer has to select Manual Exposure in order to interpret the contemporary camera's built-in light meter measurements, while Auto Aperture, Auto Shutter Speed, Full Auto, Program and other stylistic modes invoke the manufacturer's predetermined interpretation of the reflected brightnesses. However, because of the extraordinary level of instantly available reporting available via the digital camera's LCD screen – both pictorially (less accurate and more impressionistic) and via a histogram (more accurate and less impressionistic) mapping of the relative brightness values – the photographer no longer has to interpret the data imaginatively. More specifically, they no longer have to translate the data in a manner (zones) that can be easily conceptualised and thereby 'imagined' or previsualised as final print values. In digital capture, the photographer can immediately evaluate the 'actual data'. This 'digital polaroid' aspect of digital capture – as well as the economics of film-less photography – appears to encourage photographers to defer much of their imaginative conception of the image to its post-processing. But then again, this is not really that different. The Zone System also sought to guarantee an appropriate range of values, from which the desired print could be crafted (post-processed) in the analogue darkroom. It was both a form of quality assurance, as well as a way of dreaming (seeing) the world as a print. This is why it was called 'pre-visualisation'.

One thing is clear, however: the result of the drive behind contemporary camera design and manufacture is to automate this moment of previsualisation. We now have auto white balance, auto exposure, auto aperture, auto shutter speed, auto focus, auto face recognition, auto processing (typically JPEG), auto numbering, auto metadata, and so on. As Julian Stallabrass argues in his essay ‘Sixty Billion Sunsets’ (1996), relieving the camera user of manual control has the paradoxical effect of mystifying the camera’s processes. Stallabrass, for his part, romanticizes the 35mm amateur photographer’s activity as a zone of freedom, or non-alienated activity – defined against work – in the face of their technological domination by state-of-the-art electronics and the then imminent rise of digital cameras. Although Adams inevitability employed forms of automation – accepting certain preconditions of his production, using products, films, papers, premixed developers, fixers, and toners that he did not manufacture himself – he collaborated with their manufactured sensibility, accepting their qualities, and in that he gave himself over to their value-adding. In this sense, ‘innovation’ can be considered in terms of how one collaborates with or redefines the limits of available automation.

There is, however, no sense of ‘alchemy’ in digital processes precisely because every gesture is reduced to a mathematical equation, to numbers. Numbers interact in precise and predictable ways. Photographic chemistry rarely appeared so predictable, because unlike numbers, the substance of its chemistry was invisible to the operator. Analogue photographers were only able to adhere to the external conditions of production, such as the environment, its temperature, dilution and duration, within which the chemical processing happened. Hence great efforts were made to monitor and thereby stabilise the processing conditions (time, temperature, dilution, purity, and so on). Towards the final stages of processing a print, 'magical' outcomes could appear to those alert to the possibility that exceeded any capacity to predict how it would work. This was the bane of commercial photographers, but the delight of fine art photographers. Analogue photographers could not 'see and therefore know' the analogue equivalent (atoms and molecules) of today's digital numbers (that anyone can read). Human micro-blindness hid the chemical 'truth' from photographers, so they were encouraged to work harder for the revelation. For example they watched carefully the progression of a chemical toner and immediately arrested its progress when, suddenly, an effect beyond their imagination – or what they were searching for – appeared. Their limits of perception allowed what was happening in the processing tray to assume a magical status. While the electrons in digital processes cannot be 'seen' any more than the molecules of chemical processes, there is an indexical measure of them – that is, they can be counted and their effects numerically accounted for.

Half Tone

One important aspect of photography falls outside Adams' ambit: the distribution of images. Modern distribution requires two factors: mass production, and speedy dissemination. Talbot had already imagined a system of producing intaglio prints from photographs. Indeed the 1840 Talbotype was itself a print medium: as many prints as desired could be drawn from a single negative. But when in 1855 Alphonse Louis Poitevin discovered that bichromated gelatine reacted to light by hardening, the way was open for printing from photographs and their truly mass circulation embedded in print media like magazines. Relief printing methods involved exposing the gelatine (and substitutes including treated albumen and fishglue) to the negative, etching out the unexposed areas and inking the raised surfaces. The half-tone process interposes a screen between the original and a new photograph of it, giving the effect of a grid of dots of varying size, depending on the depth of the tone. This process adds more tonal variation, although to get good greys requires such fine dots that they can only print to the best chalked-faced art paper, whence the relative crudity of newspaper reproductions compared to those in expensive magazines and books.[v]

The second critical factor in the distribution of images is the speed with which they can be delivered from the site of an event to the organs of mass publication. In 1900, *Pearson's Magazine* published an article (Cook 1900) on the experiments of Edward A Hummel, of St Paul's, Minnesota. Hummel drew images using non-conductive shellac, and scanned his drawings with a conducting point connected to a telegraph. A matching plotter at the far end could replicate the breaks in the circuit as a plotted surface. The results, judging by *Pearson's* images, were relatively crude, and Hummel doesn't appear to have developed anything that could deal with greyscales. The German scientist Arthur Korn in 1907 demonstrated a far more ambitious machine, based on the light-sensitive properties of selenium, which conducts electricity better in the light than in the dark. Korn shone a lamp through a pierced grill onto a film wrapped around a cylinder in which a revolving selenium cell then conducted more or less electricity to the telegraph according to the amount of light it received. The remote receiver reversed the process to expose another piece of film.

The process was sufficiently successful for Korn to open offices in half a dozen European cities, although the time required to complete an image, the restricted distances over which it could travel, and the tendency to smear, streak and blur were obstacles to its widespread adoption. Improved by Edouard Belin, who was able to couple a photocell with telephone transmission, the basic technology was in place for what would eventually become facsimile transmission: fax machines. Press photography however required something quicker, and with greater resolution. Most histories point to the competition between Bell Labs and AT&T in the mid-1930s to develop a satisfactory industrial application, the race decided by Kent Cooper, senior manager of Associated Press, in favour of Bell's Wirephoto system, which transmitted a large photo of survivors of an Adirondack air crash to twenty-five cities at 3am, New Year's Day 1935: a succinct ideogram – air travel, crash, wilderness, network communications, news – of modernity.

What these printing and transmission technologies share is a migration from the line to the grid as their basic tool. Texture is no longer emulated by crosshatching, as it was in intaglio printing, or random, as in mezzotint and stone lithography, but regularised in the meshwork grid of half-tone screens, and standardised in time by the necessity to match scanning speeds at sender and receiver points in wire-photo and fax transmission. Abandoning Hummel's line-based approach for the grid system matched the requirements of printing with those of transmission, where a linear scan could easily be appropriated for the rectilinear mash of industrial lithographic printing. Manipulating dot size and shape, the distances between dots, and later the relations between primary subtractive colour dots, allowed a great increase in the sheer number of images in circulation at acceptable resolution. Indeed grain remains a major signifier of factual status, for example in images drawn from CCTV or telephoto paparazzi snaps of celebrities. Some kind of compromise, however, had to be reached, a compromise that will bring us back to Adams' distrust of automation in photography. His distrust was based on a lack of conscious craft on the user's behalf, or the blind acceptance of a point of view, aesthetic judgement, or technical interpretation derived not from the imagination but from either the apparatus itself, or the subordination of the apparatus to the world as given, what we would now Latinise as data.

Photography, Language and Logic

What is a photograph?

> It is an image created and distributed automatically by programmed apparatuses in the course of a game necessarily based on chance, an image of a magic state of things whose symbols inform its receivers how to act in an improbable fashion (Flusser 2000: 76).

Vilém Flusser's definition is comprehensive, if densely packed. From the standpoint of the camera, the heart of the photographic apparatus, human users are mere functionaries. The real work is done by the camera: users only play with it, but their play extends the capacities of the apparatus. From the perspective of the photographic apparatus, society is only a feedback mechanism for improving its functions. Automation is intrinsic to the apparatus. Once designed, the camera operates according to the program written into its structure. This automation not only abstracts values from the world, but reconstructs the world as information (Flusser 2000: 39). Following Shannon and Weaver's (1949) mathematical definition of information as a ratio between probabilities, Flusser sees the camera seizing not the world but an abstract 'state of things': data. Information depends on the balance between repetition and novelty. The human user and the world the camera observes only add improbability, chance, to the mix, increasing the amount of data which it can convert into photographs. The 'magic' of the definition describes the way photographs, in their abstraction, produce images, not of the world but of concepts (such as 'states of things'), concepts which then program society ‘with absolute necessity but in each individual case by chance' (Flusser 2000: 70). Photographers are functionaries of an apparatus which, if analysis is extended back far enough, reaches into capital, corporations, politics and economics, a nested series of black boxes each governed by an elite of functionaries who nonetheless are prisoners of their own apparatus. Designed to work without human intervention, cameras program both photographers and viewers in a determinist vision which comes close to Jean Baudrillard's (1975) apocalyptic vision of society as self-replicating code.

For Flusser, codes embedded in any apparatus feed on human use to produce new combinations to assimilate into the apparatus itself. This more general application of the word apparatus includes not only the mechanical device but the ensemble formed by manufacture, clubs, publications, galleries, newspapers and magazines, people and their institutions. Flusser's 'apparatus' is an institution: an ordering of social interactions that produces its own type of language (discourse), its own mode of knowledge, its own idea of truth. Unhampered by moral judgements external to its own operation, its goal is maximal efficiency. The apparatus operates in and as a regime of power, in much the same way as the clinics, asylums and prisons investigated in Michel Foucault's early writings[vi].

According to Flusser, before photography, all thought was verbal. Photography, he argues, is a visualisation of language. Digital photography, by extension, extends the verbalisation of perception by mathematising it. We know from Saussure (1974) that language is based on difference, and that that difference is negation: X is X because it is not Y. Language's intrinsic capacity for negation extends to negating what is empirically or perceptually given. Thus language asserts human independence from what is given to it by way of environment. Numbers are an outgrowth of language. From counting, number has developed to be abstract, counterfactual, independent, and negating – the same qualities as language itself. The calculus, mathematical logic and the mathematics of algorithms stem from the negation of the semantic content of sentences. Number and algorithm, as formalised in computer languages, are also institutions. Even though they do not obey exclusively the same rules (for instance, of generative transformational grammars) as natural languages, they share language's fundamental capacity for negation.

From this an important point emerges: algorithms have the power to institutionalise perception. They bring perception within the ambit of (a form of) language. The empirically and perceptually given of the non-human environment, that excess of signifiers which is a danger to humans as much as a resource for them: that world is systematically negated, pixel by pixel, in the process of enumeration. Such might be the case too with drawing and analogue photography: that they neither name nor describe, but substitute for the reality they observe. The various schools of drawing and printmaking applied such 'grammars' (Ivins 1953) between the seventeenth and nineteenth centuries. But what distinguishes digital imaging from both drawing and traditional photography – especially as defined by the practice of Ansel Adams as exemplary technician – is a semiotic, but not a semantic, change. It is the nature of the process of automation.

However, 'the process of automation' is not a stable, definable entity, confined to digital code (what literally distinguishes digital imaging from drawing and photography is not automation, but the absolute precision, predictability, and finite limits, of its numerical grid). The broader history of photographic manufacturing has been about exploiting automation in the quest for the stability and certainty that automation provides, and the profit that derives from it. The process begins several decades before Adams with Eastman Kodak's Box camera in 1888 – with its philosophy of 'you press the button, we do the rest' – and perhaps even earlier in the transition from wet-plate to dry-plate photography. Such incremental steps, via the Instamatic cassette cameras of the 1960s, and the progressive introduction of electronics into cameras in the 1970s, arrive at their destination in the 2003, when digital cameras began to overtake sales of analogue.[vii] At this juncture, the grammar of objects and the previsualised composition are superseded by the enumerated and averaged accumulation of photographic data.

Adams himself cannot be isolated from this trajectory. For instance, he served as an enthusiastic consultant to Polaroid from 1949 until his death in 1984 – a seemingly surprising encounter between a professional interventionist and the emblem of instant consumer photography (Polaroid automated all aspects of picture-taking and after 1972 effectively excluded all possibility of a photographer intervening in the developing process by producing a sealed print that developed in the light) (Buse 2008). More particularly, it was his practice, when conditions allowed or demanded, to use a spot meter, an exposure meter calibrated to sample light from a one degree arc (as opposed to the 20 or 30 degrees of arc of a normal exposure meter). The spot meter could be placed much closer to objects than the camera to get a specific sample of the light. The apparent value of light is as much a product of mental activity as of perception. Cameras, of course, do not have such equilibrating brains, and 'see' only what is there before them. The spot meter emulates the reaction of the correspondingly small area of the exposed film. Like an Impressionist seeking the colours of scintillations on water, the spot meter abstracts the value from the object, deriving from it a measurement of the light. It is the beginning of a loss of object (and thus of the subject-object relation) and its replacement with a value – a Zone number in Adams, usually a hexadecimal colour code in digital imaging). Thus the semantic world of objects begins to be replaced by an arithmetical world of measurements. The averaging of these values in half-tone, and their automation from Box Brownie to mobile phone cameras, is meticulous. Low resolution film cameras, from the Box Brownie to the Instamatic, favour norms established in manufacture (notoriously Caucasian skin tones [Winston 1996]). The specification of the stored record of the image – that is, the particular qualities of the latent image – determine the results of an automated printing process.

When they become truly enumerated in digital imaging, the pixels become elements in 'a language without a code', in the sense that there is no longer a grammar to govern the interactions between pixels. Concepts of 'in front' and 'behind', 'figure' and 'ground' no longer signify. The image is no longer an image 'of' but a pure surface. More, that surface is now a numerical matrix that algorithms can redefine at a single point, across the whole surface, or at any intervening scale. The various realist aesthetics that had been under attack for a hundred and fifty years since Symbolism and the advent of advertising have joined hands with the mathematicisation of the image to abandon realism – fidelity to either the empirically given or to natural perception of it. Indeed, the mathematicisation of the image was already formalised in the nineteenth-century by Ferdinand Hurter and Vero Charles Driffield (1890), who brought quantitative scientific practice to photography through the methods of sensitometry and densitometry. Their quest to describe the relationship between exposure and development in silver halide emulsions was not in order to abandon realism, but to aid in its indexical reproduction. Today, it is true that old realist aesthetics remain in place, that scientific measurement is also a realism, and that it is ideologically convenient to retain the belief that images record reality. The link between imaging and empirical environments has not been severed: it operates in a kind of subjunctive mood that lies between seeing and visualising, between representation and visualisation, between image and imaginary.

There is a particular strength to the photographic which enables this maintenance of a subjunctive realism. When Adams speaks of visualisation, he refers to light values. What the Zone System respects is the difference between values in a field of view. When digital cameras add hue and saturation (see the following section on colour), they too are less interested in the specific hue-saturation-value measurement of each pixel, and far more in the relationships between them. Such differences, expressed as differences between hexadecimal values, are in dialectical terms relations of negation ('X is X because it is not Y'; a zero is a zero because it is not a one). Digitisation of imaging is a move away from the object relation towards, in the first instance, the new objectivity of scientific measurement, which is itself an abstraction from language in the form of algorithm and calculus. Adams' spot meter is therefore a crucial step in the assimilation of artisan photography to the digital. But even as it does so, it opens up a contradiction inside the linguistico-mathematicisation of the image.

Unlike drawing, or even the assemblage of form from line and texture in intaglio printing, photography is then not, as Flusserian apparatus, interested in objects. Hence Adams' use of the upside down image in the ground-glass viewfinder of his view cameras: his interest lay not in things but in values. The work of earlier artists like László Moholy-Nagy and Aleksandr Rodchenko, who championed the use of bold simplified forms, dramatic vantage points and close-ups, prompted Walter Benjamin to suggest that “a different nature opens itself to the camera than opens to the naked eye” (Benjamin 1973: 238). Moholy-Nagy laid out the crux of the ‘New Instrument of Vision’ in his seminal 1925 text *Painting, Photography, Film*, noting that “the modern lens is no longer tied to the narrow limits of our eye” (Moholy-Nagy 1969: 7). Viewing a photograph commonly gives the impression of witnessing an event, because photography *constructs* the moment of the exposure *as* event. Until it is considered, a situation is only an aggregation of matter and motion. Only when it is considered, as it is in the act of visualisation, does it become an event, something to which meaning attaches, and which, being meaningful, becomes the grounds for some subsequent flash of understanding, decision or action. Photographic consideration takes the given and turns it into potential, the hallmark of an event. Henri Cartier-Bresson's ‘decisive moments’, Robert Capa's implication through camera shake of the intensity of witnessing, and Adams' wilderness compositions alike take merely given situations and extract from their raw material the conditions under which they might become other. The situation – which embraces environment, photographer and machinery – becomes event by its disturbance of habitual indifference. An Ansel Adams print becomes an event in that it presents the situation otherwise than it is given to an unconsidered gaze. It sees otherwise, revisions seeing, invents new ways to see. In this sense it fulfils the formal expectations introduced in the 1920s by the ‘new photography’ movements in Germany and post-Revolutionary Russia, however different they might appear.

Digital image capture does not require this process of visualisation, of consideration. Flusser's automatic apparatus instead deploys logic, where logic retains its philosophical role of abstracting from any particular argument ('Socrates is a man; men are mortal; therefore Socrates is mortal') the non-specific bones ('If A is B and B is C, then A is C). When it is applied as a program, as Flusser argues occurs in photography, logic automates. Digital logic abstracts numbers from the infinitesimal flux of the world. It undertakes to reproduce any given situation according to programmed instructions, without consideration, and therefore without the possibility of bringing about an event. The purpose of digital image manipulation is control over the image, not the conversion of given situations into potential events. To some extent, as we have seen, all images undertake a level of abstraction from what is given to sight. To understand how and why digital logic's abstraction is more complete than previous forms of image-making, we need to understand the particularities of our new numerical tools.

CCD and the Politics of Number

The CCD chip of a digital camera comprises a p-doped (positively charged) thin crystalline lattice deposited on a transmitting layer. Light arrives from the lens onto the lattice, each cell of which acts as a capacitor accumulating an electric charge according to the amount of light, or more technically the luminance, arriving at that cell. The array is linked to a control circuit that instructs each capacitor to pass its charge on to its neighbour. The last capacitor in the array then passes its charge to an amplifier that converts the charge into a voltage. The process is repeated until all the charges have been converted to voltage, digitised, sampled and stored by the underlying CCD semiconductor (CMOS chips used in some still cameras are a different class of semiconductor but rely on the same type of light-sensitive array). The majority of modern CCDs use a buried-channel design, where areas of the silicon substrate are implanted with phosphorous ions giving them an n-doped (negatively charged) designation. These areas act as channels through which the electric charge generated by the light-sensitive upper layer will travel. The actual capacitor layer lies on top of this buried-channel layer. On top of them is a layer comprising polysilicon gates, perpendicular to the channels. The channels are separated by oxides that stop charge flowing from one channel to the next, while the gates control the flow of charge from the capacitors towards their destination. Lying on top of the layers, immediately above the focal plane, lies a Bayer mask, which for every four pixels filters one red, one blue and two green, on the basis that the human eye sees better in the green area (the green closely corresponds to the luminosity function of human vision). Since the filters exclude the other two colours, the light reaching the capacitors is diminished by the transmission characteristics of the filter, and the information is stronger for luminance (value) than for hue or saturation. One solution to this loss of colour resolution and light intensity is to use 3CCD technology, which allows actual, not interpolated, RGB values to be recorded. Another solution, using a rotating filter, is only useful for objects that do not move. In sum: light is organised by the filter or prism, and gathered on a grid during the exposure time. The information in the grid is then passed through the system of gates and channels in ordered array to its conversion, via voltage, to stored data. The charge-coupled device operates as a kind of clock. The exposure charges the lattice, but the charge is drained from it down ordered channels in lockstep units. The chip moves its data from spatial to temporal and back to spatial ordering. Without the clock function allied to the interlocking grids, the charge would mingle and pour out in no order at all, chaotically, as noise or more specifically as heat, since these are close relatives of solar panels. The CCD imposes a very specific order, or a pair of orders, on the light that it gathers. This is characterised by whole-number steps of equal unit duration and area. The result is an array of discrete, ordered units.

These units are achieved principally in the design of the crystal lattice, which itself is grown on the chip which, acting as a seed crystal, ensures that the lattice orientation and structure are identical to itself (as opposed to polycrystalline or amorphous layers, which have no long-range order). Unlike the grains of silver halides in photographic film, the order of the molecules reacting to light is the product of design, specifically of an arithmetic design based on whole numbers. Thus the 'grain' of a digital image is already arranged in the form of a grid. Each cell of the grid reacts to the light falling on it, but does so by averaging the different wavelengths that reach it across its area. Recalling that the range of greens visible to the human eye fall between wavelengths of 520 to 570 nanometers, we have to recall that the process of averaging across that 50-nanometer field involves every shade of green, a field which experience tells us is not susceptible to whole-number division, but is a continuum. The ordering is to some extent dependent on the density and light-sensitivity of the cells. Lower density and light-sensitivity results in noise, especially in low-light conditions.[viii] But contemporary CCD chips are more light-sensitive than normal photographic film, so that even with the loss of light due to Bayer masking, the signal to noise ratio is high. This creates a quandary for digital imaging similar to that addressed by Adams' Zone System: how to correlate high contrast subjects. Areas in deep shadow appear not as low density on the negative, but as noise, random deviations from the true value. To describe these pixel units as points is incorrect: consumer CCD pixels are typically 7 to 13 micrometers, though some new models offer 3 micrometer pixels, trading increased resolution for lower capacity to hold electrons (something like 100,000 electrons in a 10 micrometer pixel). While these scales are difficult to visualise, they indicate that the number of photons reaching a CCD pixel is going to be in the six-figure range as well. However, at these quantum scales, enumeration is impossible (on the uncertainty principle), so what the stored charge measures is the photon flux over the area of the pixel for the duration of the exposure. Averaging that flux into a single value is the task that the design of the chip ascribes to these pixels.

The human eye discriminates to about one sixtieth of a degree. A pixel needs to approximate to this dimension to give a convincingly detailed image, while it also requires a grayscale of at least 256 distinct tones to give a convincing tonal resolution. A high-quality 35mm film frame contains between 12 and 20 million grains of exposed halides. Though there is considerable dispute over whether CCD cameras can match or even exceed this resolution, there are qualities that distinguish them. As we have seen in the analysis of Ansel Adams' use of a spot meter, traditional photography is also a matter of averaging, but it averages onto a random array of light-sensitive materials. In the CCD grid, in which each cell is marked off from its neighbours by the mask, by the lattice, and by the structure of gates and channels, neighbouring cells do not actually touch. This reduces the 'circle of confusion' mentioned by Adams, the bloom or smear referred to by engineers as the point spread function. But it introduces regular interruptions between areas of the image. The light-sensitive materials thus respond to light that has already been organised by the time it reaches them, and further organises the light by taking an average of its value over area and duration. The averaging function, which will be immensely important to later manipulations in image processing software, organises light into information in the form of charge and later of voltage. These values are stored in digital form, that is as zeros and ones: as whole numbers defined by the unit difference between them. This transition from averaged photon flux to unit difference indicates a peculiar property of the digital image.

The eighteenth-century epigrammatist Antoine de Rivarol once remarked:

> A man in his house does not live on the staircase, but makes use of it to go up and down and gain access to every room. The human mind, likewise, does not reside in numbers, but uses them to attain all sciences and arts (Ifrah 101)

It is on this principle that number, in the specific cases of ordering, and of digitising (ascribing numerical values to voltages), operates in the charge-coupled device of digital cameras. Rivarol's image of the staircase gives a very clear sense of the kind of numbers involved: those which count as units, and which follow one another in regular succession. We know that there are other kinds of number (pi, the square root of 2, and so on). Rivarol's point is that such numbers are of interest only as instruments in pursuit of something else, not in themselves.

The process of averaging the photon flux at a given pixel is a limit: it abstracts from the physical world a value that sums everything that has happened in that pixel during the exposure time. The unification of all previous values as a single number in the pixel charge value is such a transition. In the mathematical philosophy of Alain Badiou (2008), it replaces the foundations of being – the void, the infinite, the multiple – with a plenum, a unit value. In doing so it creates a limit for the person inspecting the result: the enumeration – the hexadecimal colour number and the pixel address – are all that there is to inspect. This numerical sign is a representation, but a representation which blocks access to what it represents, since the quantities that have been averaged are no longer visible in their sum. The sampling process normalises the photon flux, replacing gradation with the steps of Rivarol's staircase. The averaging and unit organisation of CCD imaging, its probabilistic sampling, its replacement of photon flux with units, and its placing of a limit sign between flux and representation, thus block access to the excessive multiplicity of light, and so make impossible the event that light, as excess, would make possible. The automation that Adams so feared, yet which in the instance of the spot-metre he pioneered, comes to maturity in 'the unthought basis of the ideology of the countable' (Badiou 2008: 109).

The line-scan technologies of early photographic transmission technologies are now embedded in single-line CCD chips used as reading heads in flatbed scanners. With this advance, also now used in faxes, the CCD chip's typical seriality and averaging functions have become ubiquitous. Older line-scans, starting with Hummel's pendulum apparatus, used an analogue match of time between senders and receivers. That process has now been integrated into the CCD ordering of time as a spatial grid ordered in units. Automated cameras began to simplify the averaging process first undertaken through techniques like Adams' use of spot meters, the first probabilistic management of light values. From half-tone printing's beginnings in woven fabric, and its later development of ruled glass screens, to the ordered raster grid, the transition from grammatical to statistical ordering is complete, One achievement of this process has been the assimilation of time into spatial organisation. Meanwhile, the gradations available to Adams, grounded on the one hand in the subtleties of perception and hand-eye coordination and on the other in the excess of light as both object and medium, are gradually automated. In this process, texture is standardised as raster grid, each of whose pixels are numerically specified according to an instrumental mathematics which, in averaging and enumerating, closes off the relation between representation and light, and with it the possibility of a relation between image and event.

We have been unable here to address other continuities between the analogue and digital in photography, among them issues of latency (Cubitt 2011), glass technologies (especially lenses) and theories of indexicality. To the extent that every camera relies on photosensitive reactions, whether chemical or opto-electronic, every camera records not scenes but photons, and every photographic 'image' is more properly described as data visualization. Manipulation and control of light (for example in the shared design principles of camera bodies, or in 'noise reduction' undertaken electronically or in the darkroom) order the electro-magnetic spectrum for a human sensorium. The defense of indexicality is a humanism, in the sense that it equates the reality supposedly collected by traditional photography with what a human at the same spot would have seen. Yet as we have seen, even in the heart of the realist tradition in the work of Adams, processes of abstraction were already at work. These processes are indeed embodied in changing photographic technologies, but the distinction between analogue and digital has to be traced back, before even the invention of the computer, to the second half of the 19th century, and in our instance the convergence of industrial half-tone lithography with nascent wire transmission technologies. In this sense we must understand Adams' Yosemite photographs not only as works of abstract art, but as participation in a machine or *dispositif* which, in Flusser's terms, exists to colonise for the apparatus the very space which to Adams most symbolized that which escaped it.

There remains the dialectical principle that no system is so complete that it does not contain the germ of its own negation. As Badiou argues, 'the difficulty lies in succession, and . . . there, also, lies resistance' (Badiou 2008: 81). On this principle, we can argue the counter-case to the history of arithmetic and logical abstraction presented here. Analogue photography promises an uninterrupted scale from minus-infinity to plus-infinity whose limits are the limits of the instrumentation. Digital's restriction is that the process itself, not its enactment through instrumentation, places limits or absolutes, on *every* range it works with. Despite the fact that analogue photography deploys discrete molecules and is therefore not continuous, our everyday experience of analogue photography emphasises its illusion of continuous tone and resolution. Digital processes eloquently point out this contradiction. It could even be argued that digitisation is not only a more efficient and verifiable indexing of the object of knowledge or desire, but is the logical outcome of the impetus that has driven so much photographic research, from Talbot's August 1835 imprint of the two hundred latticed panes of glass to the latest digital camera. Analogue processes pretended to continuity within the world they imaged, which in turn seemed to promise continuity between the image and the world. Digital processes may yet liberate us from that illusion, and in the process interpolate a technological vision – so often elided in analogue photography – between photographer or viewer and the world they view, and thereby liberate our tools from both our illusions and the instrumental goals of the photographic apparatus.

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[i] Although it should be pointed out that when the circle of confusion is smaller than the resolution of the emulsion, the object appears in 'perfect focus'. There is then effectively no circle of confusion, and the lens appears to have faithfully projected one point in front of it to one point behind it. Circle of confusion in this sense is also an illusion. When the circle is small enough to be confused for a sharp point, typically around 1/100" (0.25mm) at 40cm distance, we believe it is a sharp, rather than a

blurred (confused) point. In other words, the circle of confusion defines the limits of our psychophysical resolution, at a particular magnification and viewing distance.

[ii] A monochromatic viewing filter is a dark amber-orange filter (eg. Kodak Wratten Filter No. 90) that seeks to reduce, but cannot entirely eliminate, colour variations by scaling the luminance of the scene to a closer rendering to that of 'normally exposed and normally processed' panchromatic B&W film.

[iii] In the original Basic Photo series there were five volumes. The two additional volumes, subsequently but not entirely subsumed into the three volumes of the post-1980 series, were 'Artificial Light' and 'Natural Light'. In other words, subject matter and the qualities of light itself (hard, soft, key, fill, lighting ratios) also contribute significantly to photographic texture.

[iv] The Zone System as practiced and perfected by Adams is almost irrelevant to digital imaging, since the CCD's tonal reproduction curve has little relationship to a negative film emulsion (the tonal response is more akin to commercial transparency film emulsions such as Ektachrome). However, the current 'state of the art' digital Hasselblad (H3D) camera includes as an option for exposure control in 'zones', even though their value progression, and classic control points, such as zones I and VIII, are almost meaningless in digital technology.

[v] The finer the half tone screen the better the highlight reproduction. That is, more, smaller dots per square inch produce the same overall tone as fewer, larger dots per square inch, but more smaller dots produce more detail and better texture in reproduction. The same observation applies to any half tone process, where solid colours are distributed as dots of variable size, placement and dye/pigment weight, and the smaller the dot size the more dots that can be placed per unit area without changing the area's value.

[vi] In ‘The Gesture of Photography’ (Flusser 2011b), published the year of his death in 1991, Flusser is considerably more optimistic, even than the preliminary revisions of the earlier work in *Into the Universe of Technical Images (*Flusser 2011a).
Here, between periods of reflection and moments of action, photography is part of a phenomenological “project of situating oneself in the world” (280). Flusser celebrates the “reflection” on the part of the photographer, the editing process which “rejects all the other possible pictures, except this one, to the realm of lost virtualities.”
(291) However, one can legitimately ask how the editing of pictures in photographic software such as Lightroom complicates Flusser’s equation, given endless virtual versions of an image enabled by the ostensibly lossless editing of RAW files, suggesting that a photographer may now approaches the world as fluid raw material – indeed data – to be manipulated later.

[vii] The Photo Marketing Association International statistics show 2003 as the year that total US digital camera sales overtook US analogue camera sales, and that this was the first country for this to happen in.

[viii] But film has a threshold below which no signal (exposure) is recorded. This was evident even in the darkroom, where we would clearly see light hitting a print emulsion, but on subsequent processing (making visible) the print was paper white without any trace of the exposure. Digital capture has no such threshold. It records all exposure down to a single photon. Whether this is usable data depends on the conditions under which it was captured, for example, the dark current noise at the time of exposure. The limitations of a digital camera's dynamic range are full saturation (at the highlight end of the scale) and unacceptable signal-to-noise ratio (at the shadow end of the scale). Advanced noise reduction includes characterising the noise so it can be subtracted from the signal + noise, thereby liberating the signal as discrete and useful information.