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Damage into Image:

Exposing the Technics of the Digital Camera

by

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Abstract

This thesis presents an artistic and media theoretical research project focused on the optoelectronic transducer at the heart of the digital camera: the image sensor. The technics of digital vision now plays a decisive role in our lives. While the generation and manipulation of digital images using software and code is an established creative practice and the pervasive glow of the screen is matched by its visibility in both practice and theory, the hardware of digital image capture has largely eluded critical artistic attention. A fact that stands in sharp contrast to the many creative misuses and appropriations of previous visual media. The practice component of this research seeks to redress this oversight, exploring and exposing the materiality and operation of digital image sensors through a series of three experiments, appropriating the processes and facilities of optoelectronics and immunology for creative media interventions. These experiments apply destructive optical and chemical process to the sensor's surface, aiming to reveal through damaging, eroding or inhibiting their representational function. This research provides a new methodology that expands the potential of contemporary video practice by refuting the assumed technical limitations of the camera.

This practice is developed alongside theoretical research which analyses the image sensor with respect to current media theory, the philosophy of technology, and to a lesser extent, photographic theory, and science and technology studies. Central to this analysis are Gilbert Simondon's concepts of concretisation and transduction. Concretisation is used elucidate the trajectory of the sensor from research science to commercial consumer component, while transduction is used to describe the mediation of photography from our photonic environment, via camera's protocols into human visual cognition. This multi-layered transduction is peeled apart in an account of the camera's perceptual technics, arguing that its technical specificities both exceed and are addressed to the limitations of human visual perception. This comparison combines a media archaeological close reading of the sensor's technicity with a psychophysical account of embodied sight. I frame this encounter between technological and biological vision as what Karen Barad describes as an intra-action.

This perceptual understanding of the digital camera's operation is then used to analyse its contribution to contemporary subjectivity and its position within a political economy in which the distribution and consumption of images is playing an increasingly decisive (and profitable) role. I locate the various technics of the camera in relation to Maurizio Lazzarato's account the production of subjectivity, before analysing how the digital image operates within what Jonathan Beller describes as the attention economy, positing the digital camera as an instrument of capital and proposing a parallel between its fragmentation and quantification of pictorial space and the dividual and commodified nature of contemporary subjectivity.

What emerges from the parallel strands of practice and theory in this project is an understanding of the limitations inscribed in the hardware of the camera itself, and a series of provocations as to how they might be overcome. In exposing these limitations the project reveals the informatic basis and constituent invisibilities which underlie contemporary visual culture.

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Academic Thesis: Declaration Of Authorship

I, Stephen Cornford

declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

Damage into Image: Exposing the Technics of the Digital Camera

I confirm that:

1. this work was done wholly or mainly while in candidature for a research degree at this University;
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3. where I have consulted the published work of others, this is always clearly attributed;
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5. I have acknowledged all main sources of help;
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7. none of this work has been published before submission

Signed: ....

Date: ....

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Introduction

One can force the camera to create the
unpredictable, the improbable, the informative.

Vilem Flusser

Total visibility brought destruction which is
perhaps its condition of possibility.

Akira Lippit

If media histories were linear then perhaps the camera completed in December 1975 by Steve Sasson of the Kodak Apparatus Division Research Laboratory would have become the first digital camera (fig.1). At the time it never occurred to Sasson to define the contraption he and several colleagues had been working on for the last year as ‘digital’. It combined a lens salvaged from the parts bin on the floor below where Super8 cameras were assembled, 16 batteries, a portable digital cassette recorder, half a dozen circuit boards, an analogue-to-digital converter, and “a highly temperamental new type of CCD [charge-coupled device] imaging array” (Sasson 2007), a component that is the subject of this PhD project. The camera took 23 seconds to record an image to tape. The images were then viewed by playing back the tape on a custom microcomputer connected to a television. Sasson demonstrated this device to “many internal Kodak audiences throughout 1976” (Sasson 2007) to a less than warm reception. Although Kodak’s executives weren’t convinced there was a market for his prototype, Sasson was allowed to continue his research into image compression, electronic image storage and what we now know as digital photography. By 1989 this research had produced a marketable digital SLR, with a 1.2 megapixel sensor, but in spite of making money from Sasson’s patents, Kodak still weren’t interested.

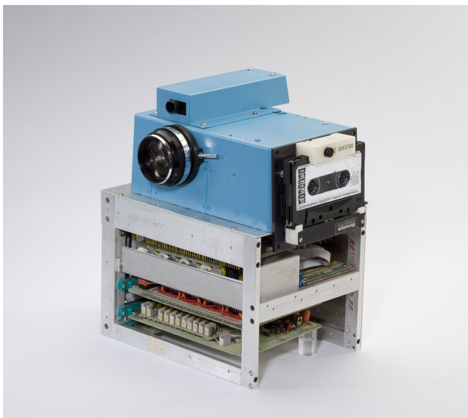


Fig. 1 Steve Sasson’s 1975 prototype

Had Sasson's first camera been taken up by Kodak it would have been a rare example of consumer technology keeping step with science. Only three years earlier, in September 1972, a representative of Bell Telephone Labs had demonstrated CCD imaging at the NASA symposium of electro-optical detectors for astronomy, to a similarly tepid reception (Smith & Tatrewicz 1985: 1226). In 1976, while Sasson was presenting his camera at Kodak, KH-11 Kennen - the first American spy satellite fitted with a CCD detector - was launched. And the following year, the discussion among the astronomers choosing the detector for the Hubble Space Telescope also swung in favour of CCDs. So it was more in spite of Sasson's research than because of it that digital cameras such as Apple's Quick Take 100 came to the consumer market in 1994, when CCDs had already been used in scientific and military cameras for nearly two decades. Hence, as Joan Fontcuberta writes: "what would have seemed a highly sophisticated spy camera less than half a century ago is now a commonplace everyday object we all carry in our pockets" (2014: 26). Friedrich Kittler's famous statement that the "entertainment industry is, in any conceivable sense of the word, an abuse of army equipment" (1999: 96-7) also rings true of the camera, though here the military agenda, fondly emphasised by Kittler, overlaps with that of research science, particularly astrophysics.

In the 25 years following its invention, the charge-coupled device or CCD has come to permanently transform the hardware of photography. The long term effects of this transformation, as it has rippled through the practices of photography and ignited wholly new image-centred regimes, are only now beginning to be assessed and couldn't possibly have been predicted by Willard Boyle and George Smith who were researching novel forms of semiconductor memory when they invented the CCD at Bell Telephone Research Laboratory in 1969. Their article reporting the invention, published in the Bell Labs Technical Journal (1970), is notably indeterminate, listing several possible applications including a memory device, shift register, delay line, and imaging array. The photosensitivity of silicon was, in other words, purely incidental to the aims of their research. Photography has been transformed by the fruits of computational research, and as a result has become informatic - more by accident than design. As Sean Cubitt writes: "particular organisational modes typical of informatics begin to impinge on modes of visualisation" (2014: 6).

The contextual transition of the CCD sketched here, from its indeterminate patent to its quick uptake as an image sensor in spy satellites, space telescopy, and also experimental physics, to its now ubiquitous presence in consumer cameras, can be understood as a process of technical genesis, which Gilbert Simondon refers to as *concretisation*. Accordingly we could look on the patented CCD as what Simondon describes as a "primitive technical object", which for him is "not a natural, physical system" but "the physical translation of an intellectual system". The multiple potential functions foreseen by Boyle and Smith typify Simondon's description of such primitive objects as "an application or a bundle of applications" (2017: 49). As the function of the CCD subsequently becomes prescribed in laboratories, prototypes, satellites, and cameras it takes on what Simondon refers to as "internal coherence", which he defines as:

> a closure of the system of causes and effects that exert themselves in a circular fashion within its bounds, and it moreover incorporates a part of the natural world that intervenes as a condition of its functioning. (2017: 49)

As the CCD concretises into an image sensor then, it can be understood as cohering around the incorporation of light energy – photons – as a precondition of its function, and around the transduction of those photons into data whose purpose is visual representation. The CCD should not however be understood as what Simondon calls an "absolute beginning" (2017: 44). Although *On the Mode of Existence of Technical Objects* (1980 & 2017) was originally published in 1958, a decade before the CCD's invention, his thesis discusses in some depth the common lineage and operation of diodes, semiconductors and photo-electric cells (2017: 44-5) and even pre-empts the impact of silicon's "transformation of the radiant energy of light into electrical current".

> The pure silicon photo-cell … is one element that hasn't yet been incorporated into a technical individual; it is still only an object of curiosity situated at the extreme end of the technical possibilities of the electro-metallurgic industry, but it is possible that it will become the point of departure for a new phase of development (2017: 70).

Although it is clear that Simondon has in mind more the industrialisation of solar energy than photographic hardware, we might also look on the CCD in the early 1970s as being just such an 'object of curiosity' to those working in the fields of astronomy, surveillance, and photography. An object that became the point of departure for numerous technical developments including the recent hot topics of machine vision, autonomous vehicles and drone warfare.

It is surprising then that the image sensor is almost absent as an object of curiosity in contemporary media art or theory. In spite of the influence of figures such as Kittler in focusing much of the debate in these fields on the autonomy of technical hardware, the image sensor remains relatively unaddressed. In the last decade many cultural critics, including Erkki Huhtamo (2004) and Cubitt (2011) have written about the most visible of such hardwares: the screen, as a locus around which contemporary subjectivity is formed. Yet, with the notable exception of Cubitt's more recent work (2014, 2015), there appears to be a media-theoretical blindspot to the role of the sensor in the production of the digital image. It seems likely that this omission is, at least in part, the direct result of our visual and tactile exclusion from its operation, as noted by Derrida with regard to computers:

> even if people know how to use them up to a point, they rarely know, intuitively and without thinking … *how* the internal demon of the apparatus operates. What rules it obeys … We know how to use them and what they are for, without knowing what goes on with them, in them, on their side. (cited in Kirschenbaum 2008: 88)

This project seeks to explicitly address the scarcity of the image sensor in both media theory and (in my view more urgently) media art. Historically speaking artists have not only been early adopters of new image technologies but also first to push these technologies beyond their intended limits: as with Man Ray and Moholy Nagy in the early celluloid era, so too with Nam June Paik and Steina and Woody Vasulka with the arrival of video. As Kim Knowles writes in her exploration of contemporary experimental film practices: "investigations into the material support are an integral part of the artistic process" (2019). Yet, in spite of the enthusiastic uptake of digital image hardware by contemporary artists, there is, with the sole exception of recent work by Julien Maire, a notable lack of critical practices looking within the black box of the digital camera. It is worth noting that this stands in marked contrast to the prolific expansion of software based image practices which have led to the creation of the new fields of Glitch Art, data-bending and to a massive expansion of the possibilities in digitally generative or interactive video work. But these fields are beyond the scope of the investigation here, which is restricted to the hardware of digital photographic capture: the image sensor. The research questions addressed in this project are therefore:

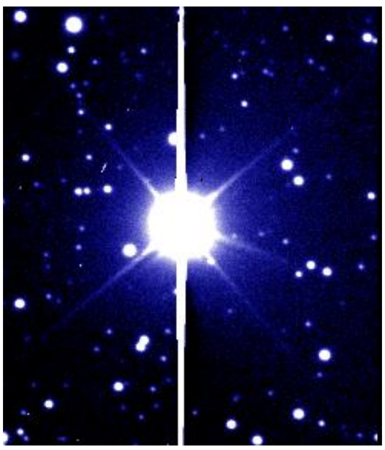
1. How can the materiality and operation of image sensors be exposed through experimental practice?
2. How has the image sensor reconfigured our relationship with our photonic environment and to what extent does its technical architecture model our contemporary subjectivity?

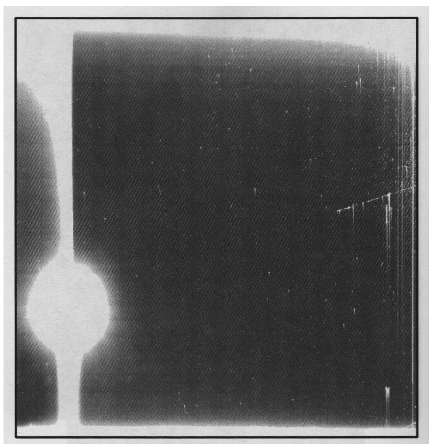
This first question is primarily methodological, rather than theoretical or conceptual. My explicit aim with this project has been to devise a new, experimental methodology founded on a materialist investigation of this hardware component that has the potential to reveal the microelectronic architecture within the image.

Saturation Trails

To answer this question I have conducted three experiments that actively expand the vocabulary of digital video. In all of these experiments (which, for reasons explained later, I refer to as *assays*) the visible spectrum of light, while present, plays a secondary role. Image sensors were exposed with an infra-red laser, hydrofluoric acid and X-ray radiation. These three assays are brought together under the collective title *Saturation Trails*. A saturation trail is a technical term used in digital imaging to refer to one of the possible effects of over-exposure in a digital image. If a pixel is over-exposed, the excess electrons will flood neighbouring pixels, usually up and/or down the column creating a saturation trail (figs. 2 & 3). A saturation trail reveals the architecture of the image or, as Susan Schuppli describes similar video artifacts, is a moment when "sensation emerges out of the technical reorganisation of the image-event … out of its material depths rather than out of its mimetic regime" (2014: 311). The assays conducted in this research project aimed for precisely these occurrences, when the trace of the process recorded by the camera is simultaneously an exposure of its representational architecture. These experiments are therefore akin to what Schuppli, in her discussion of radiological images, describes as "processes in which images do not merely represent events but are themselves continuous with and materialised as events" (2016: 161).

The value of *Saturation Trails* as a title however is not limited to its technical description, but is also metaphorical: what might we describe as the 'trail' of contemporary urban society's saturation with images? What are the consequences of what Jonathan Crary has referred to as the "uninterrupted harshness of monotonous stimulation"? (2014: 34) or, in the more outspoken words of Franco Berardi: "what emotional, psychological and existential price does the constant stress of our permanent cognitive electrocution imply?" (2009: 90). In asking these questions I make a direct and deliberate parallel between the routine visual overstimulation of today's





Figs. 2 & 3: Examples of saturation trails mediatised environments and the over-exposure of image sensors central to this project.

The three assays were chosen following research into industrial testing and accidental damage of sensors during their development as an epistemic tool of science. While an image sensor's sensitivity to both infra-red and ultra-violet light is crucial to its use in space telescopy, prolonged exposure to the extremes of radiation in these environments causes regular camera failures. Both lasers and radiation are therefore routinely used in establishing the damage thresholds and resilience of new optical semiconductors (figs 4 & 5). The laser and X-ray assays intentionally exceed opposite extremes of the visible portion of the electromagnetic spectrum. Through its astronomical use, the CCD has been vital in visualising the location of the earth in a planetary system that exceeds our sight and comprehension. These two assays propose that it might also serve an epistemic purpose by locating human sight in a spectrum that exceeds our perception. As Joanna Zylinska writes: "photography can allow us to unsee ourselves from our parochial human-centred anchoring, and encourage a different vision of both ourselves and what we call the world" (2017: 199). Throughout the thesis I therefore use the term *photonic* to refer to a spectrum of light that exceeds the visible. The use of this term is intended to open our understanding of electromagnetic phenomena beyond the semantic divisions imposed by human physiological limits. For while light is generally understood anthropocentrically as the narrow band between red and violet, the term photonic can be used to describe wavelengths into the infra-red and X-ray spectrums, and thus the complete extent referred to in this project.

The relationship between image sensors and hydrofluoric acid is more mundane. Hydroflouric is the only acid with which silicon reacts and is therefore used in the process of etching the chip with the microelectronic grid through which the image-as-electrons then flow. This etching process shares its genealogy with intaglio printmaking techniques and therefore, even prior to the image sensor, keys into a history of visual representation. In intaglio printing, acid is used to etch the inscribed lines of a drypoint image. In sensors these channels are equally integral to the construction of the image, defining the grid of its resolution, but remaining invisible. Leaving an etching plate in the acid bath for too long would result in a gradual erasure of the image. Placing a drop of acid onto a sensor's surface also causes a gradual erasure of its image but one that simultaneously reveals and destroys its sub-representational architecture. Acids also play a central role in the recycling of consumer electronics, used to leach precious metals from circuits and components by e-waste salvage workers worldwide. The use of hydrofluoric acid in this assay was therefore also conceived as recording in advance the inevitable future dissolution of these sensors that will follow their obsolescence. Following Latour's idea of the temporal folding in technical artifacts (2002 & Hayles 2017: 143), I therefore conceived of the combination of these three assays as folding the extended temporality of the sensor onto its operative surface, enabling it to record in the present the conditions of its invention, production and inevitable degradation.

The practices in these assays are therefore appropriated directly from research, manufacture and testing processes in the genealogy of the sensor. Peter Galison describes such acts of appropriation as being central to scientific methodology:

> Televisions, bombs, computers, radios, all are taken apart rearranged and welded into the tools of the physicist. And the process can be inverted: instruments from physics become medical instruments, biological probes, and communication apparatus. (1997: 54).

The making of *Saturation Trails* has entailed returning a device that trickled down from research science into consumer technology back to the laboratories where it originated, in order to dissect it, using methodologies that were central to its development, extracting it from its economic context to return it to an epistemic one.

The gesture repeated throughout these assays is that which the digital has expunged from photography: the risk of exposure. First, the image sensor is taken out of the camera, literally unfolded from its enclosure within a consumer apparatus of photonic and economic capture, exposing it to sight. Secondly, each of the three assays then seeks to over-expose the image sensor, to force it to disclose itself, to expose the abstraction at the heart of its representational operation. The emphasis here on exposure is intentional. For Akira Lippit, experimental film is "the *exposure* of cinema, the *disclosure* of its apparatuses and mechanisms" (Lippit 2012: 12, my emphasis). *Saturation Trails* seeks to do the same for the digital image sensor, to expose its abstractions and disclose its optoelectronic functions. The risk of accidental exposure central to

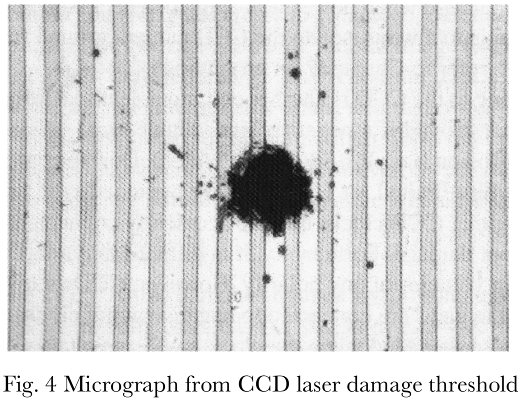


Fig. 4 Micrograph from CCD laser damage threshold test

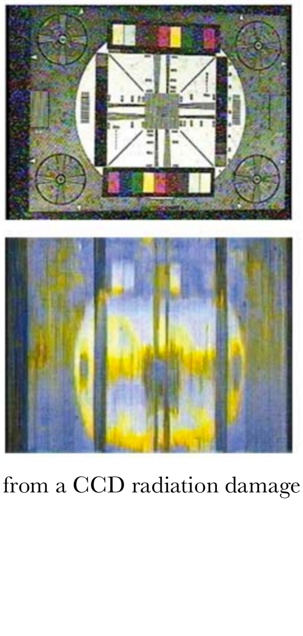


Fig. 5 Before and after images from a CCD radiation damage test

historic photographic processes has been eliminated by digitisation. The history of photography can, crudely speaking, be seen as one in which technical exposure time has decreased while attentive exposure has increased. The physical restraints used to keep early photographic subjects still in front of the camera are now replaced by an induced addiction to the portable screen. Where once we had to be fixed in front of the camera we are now fixated with its imagery. But it is also the singular photosensitivity of traditional photographic materials that provided the experimental possibilities used by so many artists, from the photograms of Moholy-Nagy to the radiograms of Susan Kriemann (2016), Martin Howse and Shimpei Takeda (Carpenter 2016: 31, 44-5). The practice of photography has been constricted and limited by its current technological form, limitations which then constrict us and our imaginative engagement with the camera and our photonic environment. *Saturation Trails* establishes a vocabulary for reconstituting the expansive and experimental nature of photography in its digital form, one based on the materiality of its central component. In these three assays I posit the camera not only as an apparatus which archives visible light but as one which has encoded within it the limitations of its users' perception in spite of an ability to reach beyond them, as an apparatus which can archive the processes of its own manufacture and those associated with its impending obsolescence. In short, as an instrument whose epistemic possibilities should not be restricted to its currently dominant consumer functions.

The tests and early applications of image sensors in scientific contexts can be understood as establishing their objectivity, an objectivity which has then become the basis for their incorporation into consumer electronics. However, in preparing the image sensor for consumer use, many of these epistemic capabilities are discarded by its limitation to the visible spectrum. Meanwhile, in scientific and military contexts, sensitivity to the extra-visual portions of the spectrum is ever more actively instrumentalised. Just as with the regulation of broadcast frequencies, power is maintained through control and limited allocation of the electromagnetic spectrum. In the varying applications of this single semiconductor there exists a technical asymmetry similar to that observed by Kittler in passenger aircraft.

> In the jumbo jet, media are more densely connected than in most places. They remain separate, however, according to their technological standard, frequency, user allocation, and interface. The crew is connected to radar screens, diode displays, radio beacons, and nonpublic channels … But the passengers … are listlessly hooked up to one-way earphones … Their eyes are glued to Hollywood movies … that all serve the purpose of screening out the real background: noise, night, and the cold of an unlivable outside. Against that there is muzak, movies, and microwave cuisine. (1987: 102)

The extra-visual photosensitivity of silicon is crucial, for example in the hyperspectral image sensors used in astronomy, satellite surveillance, biomedical imaging, and the remote geo-sensing of minerals. While for physicians capturing the movement of a cloud of electrons in a particle chamber, the CCD's dual functionality, as both optoelectronic element and memory device, meant that "the entire event could reside in the CCD" (Galison 1997: 572). But for the consumer, fixated with scrolling images posted by their peers on the screen in their pocket, a set of pseudo-interactive insta-filters for rearranging the known psychophysical limits between red and violet are all that is available. The visible spectrum has become media technical eye candy: a sliver of liquid crystal with which to screen out background radiation and political imagination.

The three over-exposures of the *Saturation Trails* assays are intended and conceived as means of rediscovering the epistemic abilities of this now mundane component and reflecting them back on itself, of both scrutinising and vandalising the mono-dimensional economic function to which the image sensor has been reduced. These assays appropriate processes from optoelectronics and repurpose them for semiconductor sabotage. As Gustav Metzger writes in *The Chemical Revolution in Art*: "We shall use science to destroy 'science'" (cited in Fisher 2014: 34). By applying Metzger's statement here to my own practice I intend the second 'science' to be understood as the economic instrumentalisation of the products of science. This folding of the sensor out of the consumer camera and back into its originary epistemic context of the lab is intended to enable a re-examination of a scientific device whose function has been popularised and largely taken for granted within the consumer camera. In the way in which I have chosen to answer this research question there is therefore an implicit critique of the determinate limitations applied to photographic practice by its current hardware.

The question may be methodological but the way in which it is addressed should be understood as ideological. In addressing the question in this way, my intention is to reframe the methodological decisions of artistic practice as political choices. To do so relies on a logic, perhaps familiar to media theorists and media art practitioners, but which is not necessarily explicitly visible in the work itself and requires some unpacking here.

At some point, incrementally, between the late twentieth and early twenty first century, an inversion occurred in the hierarchy between cultural product and technical device. To pick an arbitrary but relevant date, in 1969, when the CCD was invented at Bell Labs, we could understand the primary purpose of media technologies as being to enable the production and broadcast of cultural products. However, in the intervening years this situation has been turned on its head, leaving us in a position perhaps articulated most clearly by Hito Steyerl when she writes: "cinema today is above all a stimulus package to buy new televisions, home projector systems, and retina display iPads" (2013). In a society which has become focused upon the production and consumption of technology over and above the cultural content, fictional narratives and social commentary which they reproduce, the decisions about how we, as artists, use these technical tools are *always* political. In this context, to keep up to date with the industry standard and internalise the presentational aesthetics of cinema in the manner so often witnessed in exhibitions of video art is to perpetuate this induced inflation of the value of technology as superior to that of culture. This is not a Luddite call to arms to artists to smash our laptops and HD cameras, but rather to give greater consideration to how we use these tools. The state-of-the-art affordances of digital technologies can be turned back counter-forensically against the injustices of state power, as exemplified by the work of Forensic Architecture (Weizman 2017), we can critically inquire as to the constitutive role that they have come to play in constructing our reality – as I try to do here, they can be used for genuinely epistemic purposes to reveal that which is otherwise beyond our perception, or we can simply be seduced by them.

The Technical is Political

In the metaphorical value attached to the title *Saturation Trails*, and in the framing of the three over-exposures as creative acts of sabotage or vandalism my intention is to extend our understanding of the methodological questions of artistic practice into a political or even ideological context. This emphasis of the project is in marked contrast to some of the theoretical contexts used to frame the project, such as the media theoretical and media archaeological work of Kittler and Wolfgang Ernst, whose privileging of the specific technicities of individual media informs my own theoretical and practical approach. Unlike Kittler and Ernst, however, my argument seeks connections between such technical specificities and questions of subjectivity and political economy related to the broader social function of the image sensor. In this sense, the work of Jonathan Crary, Sean Cubitt and Carolyn Kane, all of whom are attentive to the technical specifics of the media they analyse while also, in Cubitt's own words, "propound[ing] the reconstitution of political economy at the foundations of visual aesthetics" (2014: 10), provide a more apposite precedent. In fact, as I argue here, the image sensor should be understood as a case in point of the technics of visual representation being subsumed by the logic of an informatic economy. The sensor operates through processes of extraction and abstraction, averaging, enumeration, and encoding. It extracts photons from its environment, averaging the number striking each pixel, enumerating the electrons produced in its silicon substrate before encoding them as binary abstractions. Cubitt identifies enumeration and averaging as distinctive features of data visualization, considering them inseparable from their respective political contexts: “enumeration belongs to the world of the commodity; averaging, however, belongs with a relatively new form of government, with power, and therefore with politics” (2014: 10). It is, in other words, impossible to isolate the operational protocols of media from the operating principles of society. The CCD’s informatic origin and operation might have been incidental to its photographic function but the ramifications of this image computation are extensive.

In hypothesising the existence of both an ‘attention economy’ and ‘computational capital’ Jonathan Beller arguably goes further in establishing a connection between media and political economy, albeit without a keen focus on technics. For him, cinema and television have inculcated, and social media subsequently accelerated, an economic regime centred around a distribution of and fixation with images in which eventually “the entire visual field is posited as a site of value extraction” (2017a: 137). The extraction of photons and their abstraction and encoding as photos, when repeated on a global scale, amounts to an industrial monetisation of the visible. For Beller:

> visuality and the senses have been supervened by computation and data-visualisation to the extent that thinking and critique are short-circuited as sub-routines subjugated to the programmed exigencies of machines (2017a: 143).

The theoretical chapters that accompany the practice here aim to take account of the image sensor’s role in this industrialisation of the visible, positing its technical operation and intervention in perception as both a microcosm of, and contribution to, this value-extractive process. In emphasising the connection between technical and social processes I do not mean to propose the image sensor to be the root cause of the capitalisation of images, but rather to be symptomatic of a broader cultural tendency which tends to quantify all signals, whether photonic, electronic or biological. The enumerative tendency of the camera does not originate with its digitisation, and has been noted by many of photography’s commentators, among them Vilem Flusser, for whom all apparatuses, the camera included, are calculating machines which simulate “thinking expressed in numbers” (2000: 31); and Crary, for whom photography and money are “equally totalising systems for binding and unifying all subjects within a single global network of valuation and desire” (1990: 13). Beller cites Seb Franklin in tracing photographic quantification to an analogy made by Herman Hollerith (inventor of the tabulation machine and founder of the company that later became IBM) between photography and data collection: “the enumeration of a census corresponds with the exposure … while the compilation of a census corresponds with the development of a photographic plate” (Beller 2017a: 105). Through this analogy we can see the gridded lattice that divides incident photons between the pixels of an image sensor as directly connected to the tabulation of census data pioneered by Hollerith in his use of punch cards. The social division of populations in the gridded format of the punch card precedes the photonic division of photographic space. Nevertheless, the application of this microelectronic grid to the practice of photography, and the computation of the image it enables changes the stakes of photographic mediation. This is the subject of my second research question:

> How has the image sensor reconfigured our relationship with our photonic environment and to what extent does its technical architecture contribute to our contemporary subjectivity?

I address this two-part question theoretically in two distinct chapters. Chapter 3, Perceptual Technics in a Post-Optical Epoch, gives a detailed account of the *perceptual technics* of the digital camera in comparison with human visual physiology. This chapter combines a media archaeological close reading of three technical components of the digital camera (the sensor, screen and image processing algorithms) with a psychophysical understanding of human visual perception. Attention is focused on the correlations and disparities between these equally technical systems of sight: one computational, the other biological. In order to grasp how embodied vision is modified by the internal technics of the camera, I also draw on phenomenological accounts of technical instruments, namely those of Don Ihde and, more recently, Mark Hansen.

This combination of media archaeology, psychophysics and phenomenology is not always smooth, and at times even contradictory. Ernst, for example, describes media archaeology as:

> the complementary method to media phenomenology. It does not look at media on the level of their surface effect on humans (interfaces), but rather tries to uncover the hidden agenda of technomathematical artefacts. (2013a)

Combining these complementary methods here is therefore intended to both delve into the sensor's hidden technics and to apply this understanding to its social effects on humans. Where I diverge from Ernst is in his description of these effects as 'surface'. In fact, as my analysis of contemporary photographic hardware demonstrates, these technics externalise elements of our own perceptual physiology in their design, allowing them to invisibly penetrate and construct our perceptual experience from within our own visual cognition.

The use of phenomenological method can also be seen as opposed to my references to psychophysics, particularly Helmholtz. According to Kittler (2006) psychophysics contradicts phenomenology because it measures and quantifies human perception – reducing it to a technical system rather than insisting on the primacy of subjective experience, as the phenomenologist does. Psychophysics is fundamental to media technologies, as it was only once perceptual experience was quantified in, for example, the colour vision experiments of James Clerk Maxwell, that its mediation by an external apparatus became conceivable. Psychophysics therefore provides the historic precedent for the comparison undertaken here between the human visual system and the digital camera.

A phenomenological account of the camera helps us to locate not the correlations, but the disparities between its technics and embodied perception. Berardi and Beller respectively describe computation as "a mutation in the texture of human experience" (2015: 12) and "the separation from embodiment imposed by information" (2017a: 78). Beller's language here deliberately evoking the centrality of embodied perception in phenomenology. Defining the conditions of this embodiment is contentious among the references used here, with Ihde insisting that embodied perception can only occur when the mediating instrument is transparent to our perception while Hansen argues that contemporary "embodiment is realised, and can only be realised in conjunction with technics" (2006: 20). Analysing the various components of the camera independently reveals the difficulty of establishing the boundary of embodied perception with regard to the digital camera, as elements of its technics externalise our visual perception so effectively as to confer a sense of reality upon the images they produce, while often operating so far beneath our psychophysical thresholds as to be utterly imperceptible.

There is also a friction between the sensory mimesis of the camera and Karen Barad's concept of *intra-action*, a governing principle referred to at multiple scales throughout the thesis: from the particulate intra-actions of photons and electrons in the sensor to perceptual intra-actions between subject and camera. For Barad, the agencies of the observed and those of the observing apparatus are inseparable and are mutually constitutive of any given phenomenon. So, in the assays described above, the technical agencies embedded in the camera and the laboratory equipment become entangled in the moment of the experiment: they intra-act to produce the photonic event encoded on the SD card. Equally, in the context of my theoretical argument, camera technics and visual cognition intra-act in the moment of perception, interpenetrating one another to form what Katherine Hayles refers to as a "cognitive assemblage" (2017: 115). Where I refer to externalisations of our perception then I do not imply that we *experience* them as such, but merely that they are *designed* with respect to our own physiology and are therefore intended to function as such, presuming the subject to be the definitive centre around whom media cluster. Barad's concept of intra-action refutes this outright, providing a model in which the question is not only how perception is externalised in technics but also how these technics then become internalised in us. In unraveling the hidden agendas within the digital camera, I will show how and where its perceptual technics become internalised, embodied and thus contribute to and constitute our imagination and subjectivity. Throughout this analysis we find the camera addresses itself towards our physiology and cognition, actively optimising its images for, and endearing them to, our sight.

In the intra-action between subject and photonic environment the technics of the camera dictate the visual rendering of that environment, establishing limits of photographic engagement that are discarded, smashed even, by the assays conducted here. But equally these technics establish the means by which the image constructs us as subjects, what we might consider the subjective or imaginative effects of visual media, which are the focus of Chapter 4: Subjectivation and the Digital Camera.

For Felix Guattari, "technological machines of information and communication operate at the heart of human subjectivity" (1995: 4), and images specifically constitute "a vector of subjectivation" (1995: 25), but how have these vectors shifted in the digitisation of photographic technics? The camera has always targeted its users as spectators (or, as Flusser has it, functionaries), the addition of a screen only makes this explicit, but the technics of the digital image are as concealed behind this screen as they are displayed on it. As Maurizio Lazzarato writes in his theorisation of the production of subjectivity: "the image doesn't only represent, it acts pragmatically on the real and on subjectivity, for it makes us see, intervenes, acts on what man and human subjectivity cannot see" (2014: 137).

In speaking of exactly this invisible mediation of sensibility, Guattari coins the phrase *asignifying semiotics* to denote "informational sign machines … that function … independently of the fact that they produce and convey significations" (1995: 4). The digital encoding of the image and its algorithmic processing are exemplary of asignifying semiotics, operating directly on our perception of reality while existing in a realm divorced from and inaccessible to perception. Where Guattari speaks of these semiotic systems as asignifying, Hayles (2018) has recently coined the term *cybersemiosis* to denote semiotic systems which do signify and construct meaning, but within technical systems that are then capable of affecting human realities.
The image sensor is the transducer between these domains, it samples from a partially perceptible photonic environment and speaks to an informatic environment of cybersemiosis. And the human address of the camera – its screen – transduces the informatic directly into embodied cognition.

When we look at the screen we see an image, but from the side of the camera the image never existed. From the instant of capture it is dissolved into a particulate array and the distribution of values across this array is then optimised according to an encoded knowledge of human visual physiology. These perceptual technics are targeted at a molecular level that Simondon describes as the pre-individual. The camera therefore exemplifies what Lazzarato, following Guattari, describes as *machinic enslavement*, a mode of subjectivation in which our pre-individual sensory biology is solicited by a machinic process. The biological unity of the individual is broken into its sensory, motor and emotive constituents, and as a result "the freedom, independence and autonomy of the individual economic subject are undermined … making him [or her] act and decide without necessarily accessing consciousness" (Lazzarato 2014: 97).

There are then two contradictory forces in this photographic subjectivation. The holistic image perceived has a subjectivating effect on the individual. But the perceptual technics of the camera operates on all its images and all its subjects equally. Neither individual image nor individual subject are of any consequence to a technics which operates on images at the levels of the pixel and the database, and on people at the levels of sensory perception and population. As Cubitt writes:

> The movement began in the industrial revolution's shattering of work through the division of labour which not only de-differentiated the specific forms of work but shattered the worker, who from then on was only required to perform small tasks – proto behaviours … It is this same logistical division we can see proceeding, in parallel, with the move from the treasured snapshot to the mass image, through partwork to cognitive labour and the database economy. (2017: 11)

The dividual nature of contemporary subjectivity, first posited by Gilles Deleuze (1992) and since expanded upon by Lazzarato (2014) among others, is of a piece with the internal dissolution of the image by contemporary camera technics and its subsequent disappearance in the social databases which mine our individual image intra-actions for aggregated behaviours.

• • •

The practice and theory of this project therefore address distinct questions, while both confining themselves to contemporary photographic hardware. The assays seek to discard the innate restrictions of the digital camera, to shatter the conventions of videographic practice by replacing its representative function with a reflexively epistemological one. These over-exposures force the camera to expose the materiality and operation of its sensor, reflecting its imaging function back upon its substrate. The tendency of this practice to absent the human is a direct product of the sensor's technicity as a microelectronic component whose manufacture and use involve procedures and environments, appropriated here, which are quite simply hostile to humanity. This absence is also countered by the centrality of the human subject in the theoretical argument. Here too, revealing the sensor's operation is the central question, but this question is addressed perceptually and socially, drawing a connection between technics and politics. In establishing this connection I propose that the image sensor is an example of what Lazzarato describes as “a material infrastructure that generates an ideological superstructure” (2014: 57). In the context of the networked consumer camera the image sensor serves the extractive logic of capital. The practice then exposes the sensors abstraction while the theory exposes its extraction, and, for Beller, “abstraction and extraction are of the same act” (2018).

The remainder of the thesis is split into four chapters, the first two addressing the practice and the latter two expounding the theoretical argument. Chapter 1 comprises a brief methodology in which I locate this project within a context of artistic practice before discussing the rationale for specific methodological decisions. Chapter 2 opens with three texts each describing one of the three assays of *Saturation Trails*, before contextualising these assays and the videos they produced in a theoretical framework. This chapter acts as a bridge between practice and theory, it addresses the sites, techniques and concerns of the practice while referencing some of the theoretical ideas developed thereafter. The writing deliberately resists linear academic argumentation and instead uses endnotes in order to retain the sometimes messy correlations between theory and practice. In Chapters 3 and 4 I then address the two parts of my second research question. Finally a conclusion draws together the distinct conclusions to the two questions arrived at through practice and theory, respectively.

Chapter 1

Methodology

> We might ask ourselves who can achieve an understanding of technical reality and introduce it to our culture? … a sociologist or psychologist of machines, a person living in the midst of technical beings as its responsible and creative conscience.
>
> Gilbert Simondon

The scope of this project is deliberately restricted to working with, and writing about, digital image sensors. This decision to address a single technical component of which I had no previous knowledge or working experience was made for several reasons. The internal technics of the camera has undergone a complete reinvention in the last 30 years, and the image sensor lies at the focal point of this transformation. On the one hand it seemed important to address what has become such a pivotal technology in contemporary media, while on the other it redresses an omission among current media art practice: an exploration of the digital image through its hardware.

This new materiality of photography is inaccessible to its user: the digital camera conceals its operation in a manner typical of all digital technologies. In some respects this has enabled an unprecedented expansion: in the ease and degree of post-production image manipulation, the range of basic exposure controls within the camera and the speed and convenience of image transmission. These freedoms are, however, all built on a presupposition of a normative mode of photographic capture. As such the digital camera materially mitigates against experimental practice. The explicit aim of this project is to redress these in-built limitations through an exploration of alternative modes of digital image production. This exploration specifically concerns material interactions with the hardware of the sensor itself: not with focusing light *onto* its surface, but with inscribing, penetrating or etching *into* this surface; not with the sensor's ability to image its environment, but with finding environments and conditions in which the sensor could be provoked to reveal its own image. This materialist approach exposes the relationship between the sensor's physical substrate, its electro-optical operation, and the encoded images they combine to produce.

Ariella Azoulay draws a distinction in the history of photography between "the known figure of the photographer" and "those who investigate … and analyse various optical, mechanical, technological and conceptual aspects of the appearance of the seen." (2014: 48). For her

> the photographer is a skilled and talented operator of a device that serves him as a black box. Usually, he or she has no interest in investigating and developing that which has become photography (2014: 41)

The work conducted on this project responds directly to the lack of artistic research posing these investigative and analytical questions with regard to the hardware of digital photography. All of this work begins from an active and literal deconstruction of the black-boxed digital camera and then proceeds to deconstruct the sub-perceptual architecture of the sensor itself. The work could therefore be understood as what Laura Marks has referred to as 'aniconic art': "art is aniconic when the image shows us that what we do not see is more significant than what we do … the most important activity takes place at a level prior to the perceptible image" (2010: 5). In this dynamic, the camera is transformed from an instrument of observation to an object of observation; its ability to reveal becoming reflexive as, under the extreme conditions applied to it, it discloses its own mode of operation. If the camera can be understood as an epistemic or forensic instrument then I seek here to fold this ability back on itself.

The centrality of media hardware in my artistic practice follows a tendency described by Caroline Jones as "the internalisation and incorporation of the discourse of technology into artistic production" (1996: 358). Previous projects have involved a wide variety of audio-visual media including: cassette and reel-to-reel tape machines, turntables, compact disc players, 35mm slide and 16mm film projectors, CRT televisions, and optical disc drives. In all of these instances the central concern has been to subvert the functional assumptions we make of these technologies by negating or replacing the content of the medium. This repeated questioning of assumed use is described by Michael Dieter as "the deferral of judgement that drives praxis into a direct confrontation with presumptions" (2014: 219) and is, for him, a key aspect of what he terms 'Critical Technical Practice'. The functional re-engineering of these works has often been reflexive, enabling the medium to amplify or project its own mechanical or optical conditions. What has emerged from this body of work as a whole is a study of the varying conditions of mediality, a practice closely associated with that described by Hertz & Parikka in their *Zombie Media* essay (2012), as both a study of media materiality and a critique of planned obsolescence.

During a residency at no.w.here film lab in 2013 my inquiry took a seemingly permanent turn towards optical technologies that forms the immediate context for this project. As a result, one of my core aims here has been to find a means of working with/in digital image hardware akin to the materialist practices of experimental film or early video art. In her recent chronicle of early video art Ina Blom (2016) draws a direct connection between the epigraph from Simondon above and the fertile period of media experimentation epitomised by artists such as Nam June

Paik or Steina Vasulka[1] stating that "only a person taking on the society of technical beings as its responsible and creative conscience can be a sociologist or psychologist of machines" (2016: 26).

Methodologically speaking this practice can be appositely described by Erkki Huhtamo's neologism of *thinkering*[2]: a compound of thinking and tinkering that he uses to describe Paul De Marinis' practice (2010: 39). This notion of thinking through making is intentionally contrasted with more traditional textual and linguistic notions of research. Agamben, for example, describes "terminology" as "the poetic moment of thought" (2009: 1). But, for those working in numerous fields of practice including the arts, architecture and experimental science, 'the poetic moment of thought' often occurs not through and amongst language but through technics and amongst materials. Karen Barad, in her sustained critique of representationalism's "failure to take account of the practices through which representations are produced" (2007: 53), poses the rhetorical question "how did language come to be more trustworthy than matter?" (2007: 132). Artist Natalie Jeremijenko expresses a similar doubt, echoing Heidegger's definition of thinking not as linguistic but manual: "I think thinking is handiwork, which is why I use the term "thingker" … I can't make sense of the world in theoretical terms without the materiality of what actually works" (Hertz 2012). The central methodology of this project is not textual but technical: its poetic moment occurs not in terminology but in technology.

That said, this project has been more circumscribed by the written word than any previous work. Firstly, as a result of the operative opacity of digital technologies in general and image sensors in particular, any elucidation of their technical operation must begin at the written word. For someone without access to the facilities of optoelectronic research or industry, there simply is no material means of comprehending this component. Our recourse is to reading. I have regularly engaged in technical research into the manufacture and operation of the sensor, and it is directly from this research that the three practical methodologies used (infra-red lasers, hydrofluoric acid, and x-ray irradiation) were identified. But, more importantly, the project as a whole has been conducted through concurrent academic and artistic research and it is through this mutually informative combination of methodologies that the work has developed.

In *Making* Tim Ingold addresses the opposition between theory and practice, text and matter, reason and intuition. Ingold describes this opposition in terms of that between anthropology and ethnography. In the former, one makes a study *of* a people by reading *about* them whereas in the latter one studies *with* people in order to learn *from* them (2013: 3). In this project, this distinction is exemplified by two consecutive photographs taken in May 2016 (figs. 6 & 7) while on a residency in Sokołowsko, Poland. During this residency my time and space were divided

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[1] Following my performance of *Destruction of an Image Sensor* in Bristol (November 2017), Malcolm Le Grice made this comparison between my work and theirs.
[2] This analogy has also been made of my practice by Andrew Prior in his PhD Thesis 'Mediality is Noise: The onto-epistemology of noise, media archaeology and post-digital aesthetics' (2015: Aarhus University).

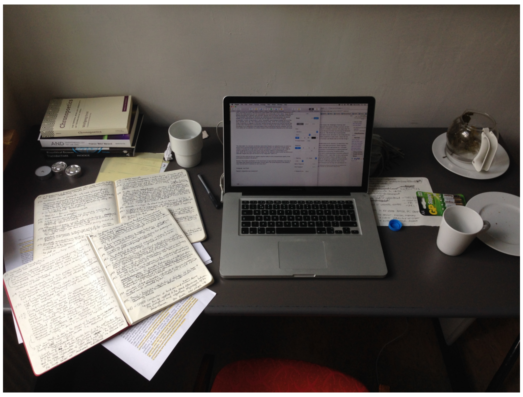


Fig. 6 Theory desk

Fig. 7 Practice desk

between writing and making. Although this division has never since been so clear as in the daily cycle of this period, a similar relationship has persisted throughout the project.

It is worth emphasising that although these activities have co-existed throughout the last three years it is rare that they have directly informed one another. The practice does not illustrate the theoretical argument proposed in the subsequent chapters here, nor does it prove any of the conclusions reached through the theoretical research and textual reasoning. In fact I would go so far as to say that proof, argument and conclusion are all anathema to the mode of creative practice used in this project, one closer to what Ingold describes as the “art of inquiry” in which

> every work is an experiment: not in the natural scientific sense of testing a preconceived hypothesis … but in the sense of prising an opening and following where it leads. You try things out and see what happens. (2013: 6-7)

One might even apply this literally to my prising open of the camera, an action undertaken repeatedly throughout the project, with continually higher resolution cameras. Furthermore, the theoretical writing and the practice address distinct questions, neither of which, I would argue, are capable of being answered by the opposing methodology. Certainly one could study the subjectivating effects of the networked-camera-computer using both anthropological and ethnographic methods: for example by reading *about* digital cameras and social media or by spending time *with* people using these technologies (as indeed we all do). But to effectively construct such an argument through practice, which is to say ethnographically, places the work in either a sociological, journalistic or documentary mode. While this may partially explain the current popularity of documentarian methodologies in contemporary art, my interest here was in maintaining the media archaeological approach of my previous practice, in scrutinising the camera’s architecture rather than its users in search of clues as to how its own materiality controls and manipulates both its subject matter and, as I will later argue, its subjects. This methodology of close technical scrutiny is not exclusive to media archaeology, but is also fundamental to Simondon's technical philosophy and to Hayles' thesis of technical cognition in which she insists that "only if the system in question is interrogated closely and researched thoroughly can the inflection points be located" (2017: 204).

It is possible that the limitations of theoretical media archaeology noted by Hertz and Parikka, namely that it fails to connect its "methodology of lost ideas, unusual machines, and re-emerging desires … to political economy or ecology" (2012: 427) are also limitations of such creative practices. But, implicit within the three willful acts of creative (albeit measured and careful) vandalism that comprise *Saturation Trails* is a critique of the functional presumptions and technical standards which comprise the camera. In Dieter's essay on Critical Technical Practice he describes critique as "always formed within pre-existing circumstances and settings but arises through *voluntary disobedience*" (2014: 219, my emphasis). The three assays discussed here combine the circumstances of my creative practice with the setting of the laboratory, a relationship I will discuss briefly below, but their critique – the context within which they can be understood as disobedient – is addressed only to the camera and the industries which produce it and profit from its images.

To remove the casing screws from a new electronic device has become a radical act for a consumer to undertake (Hertz and Parikka 2012). Where once amateur radio magazines were marketed at hobbyist builders of their own media devices, to remove a screw now voids your warranty. Perhaps in Asia where a sizeable portion of the population are employed in the manufacture, assembly and disassembly of electronics, replacing individual components of a malfunctioning machine at home might be conceivable, but in western Europe and North America consumers are only granted access to external functionality. Flusser diagnoses this distinction between exterior and interior functionality as "two interweaving programmes in the camera, one of them motivates the camera into taking pictures, the other one permits the photographer to play" (2000: 29). The interior functionality of the camera, its programme, is beyond the reach of the photographer, and for this reason, according to Flusser, "the camera functions on behalf of the photographic industry, which functions on behalf of the industrial complex" (2000: 29). The action repeated in this project of removing the sensor from the camera's interior, and testing it to the point of destruction, is to disobey this fundamental duality in the camera's operation. If, as Flusser writes: "power has moved from the owner of objects to the programmer and the operator" (2000: 30), then the experiments conducted here are attempts to subvert the presumptions made by the photographic industry and inquire into the nature of the programme on which the camera is founded. It is for this reason that the theoretical argument in Chapters 3 and 4 is addressed to the context of media theory rather than that of art practice.

Denisa Kera also refers to concepts of disobedience in contextualising hardware hacking practices, specifically using Steven Woolgar's idea of *ontological disobedience* which she paraphrases as "a form of perpetual rebellion against social and other conventions in the name of probing their conditions, limits and possibilities, which are often technical and economic" (2012). Woolgar distinguishes two different types of disobedience: instrumental, and dynamic or ontological. For him, instrumental disobedience is that which "is designed to bring about change, and in particular a move to an alternative stable state" (2005: 313). Whereas ontological disobedience

> takes the form of an enduring restlessness, discomfort, dissatisfaction and scepticism … The disobedience envisaged here is intended to be constantly unsettling, challenging, destabilising, but with no specific end in mind. It provides a reservoir of continual questioning. (Woolgar 2005: 313-4)

It is with this notion of disobedience and critique as a continual questioning that I would align my practice as a whole and this project specifically. Although less explicitly political, this project therefore has common concerns with some of the projects recently collated by Garnet Hertz, who also refers to disobedience in titling his collection *Disobedient Electronics* (2017). I will return to this idea of the work as technological critique at the very end of the thesis, when drawing together the otherwise distinct threads of theory and practice but there are other aspects of my methodology that require elucidation before continuing.

In Ingold's definition of inquiry, we have already seen a distinction between scientific definitions of experiment, which involve testing a preconceived hypothesis, and artistic or anthropological ones, which are open to whatever may occur. In describing the experiments undertaken during this research I have adopted the scientific term *assay* in reference to the scientific facilities and processes used. The assay is an apposite framework for these experiments for several reasons. In biology and radioimmunology, assays are used to test the response of an organism to an unknown substance and to then isolate the entity thought to have caused this response (Latour and Woolgar, 1979: 58-9). Although the meticulous rigour of a bioassay is absent here, these assays aim to test the response of the image sensor under a set of unknown conditions and, in so doing, to render the sensor's opacity transparent. In addition, Latour and Woolgar contest that the bioassay "is not merely a means of obtaining some independently given entity" but "constitutes the construction of the substance" (1979: 65). They go on to say

> We do not conceive of scientists using various strategies as pulling back the curtain on pregiven, but hitherto concealed, truths. Rather, objects are constituted through the artful creativity of scientists (1979: 129).

John Law expands Latour and Woolgar's reading of scientific method, stating that "reality is neither independent nor anterior to its apparatus of production" (2004: 32). This position echoes my own argument below that the digital camera, rather than objectively depicting an external reality, is instrumental in constructing the image and is therefore constitutive of, rather than objectively representative of, our environment. If the assay constitutes its (bio-)object and the camera its apparent reality then we could consider the three assays that comprise *Saturation Trails* as re-constituting the camera along new and unfamiliar lines. These assays call into question many of the presumptions that we might have made about photographic objectivity by revealing the inscription of the image in the physical substrate of silicon. They demonstrate the consumer camera to be an instrument sensitive to radiation far beyond the limits of the visible, one whose chromatic response is automatic and does not correspond to but exceeds human colour perception; an instrument whose prerogatives are to normalise any given signal within a pre-defined range of desirable luminance and chrominance.

The specific assays used in *Saturation Trails* were chosen for their direct involvement in the manufacture or testing of image sensors. These three processes should therefore be considered as having been materially constitutive in the historical development of image sensors. Both laser and acid assays were conducted using the facilities of the Optoelectronic Research Centre at the University of Southampton. The third and final assay was conducted at the X-ray Irradiation Facility of the Centre for Cancer Immunology at Southampton General Hospital. These laboratory environments have also informed decisions about how the work is then exhibited. The cluttered environment of the FAST Lab (Femtosecond Applications of Science and Technology), in which instruments, machines, lenses, computers and other devices are bricolaged together into a scientific apparatus (see portfolio pp. 9-11) was crucial in informing the construction and appearance of the tripod used to display the Laser Assay. This contraption combines a macro tripod, double monitor mount, PC power supply, two Raspberry Pis, amplifiers, and speakers with two stripped down computer monitors.

The horizontality of the laboratory bench, and hence also the image sensor, was notable in all three assays, particularly as this upwards perspective contradicts the camera's customary vertical or downward perspective. The horizontality of the screens used to display Acid Tests #3 & #4 (see portfolio pp.56-7) is intended to reflect this condition while also maintaining the illusion that the drops of liquid captured in the video are actually on the surface of the screen – that the damage displayed is occurring live. The disused CCTV equipment found in the Irradiation Facility (see portfolio p.43) is evoked in the use of CRT broadcast monitors to display all of the standard definition footage. And the dominant presence of lead in this room informed my decision to amplify the audio recordings of the contamination monitor through a sheet of lead, its dampening effect on the sound echoing its depletion and containment of the radiation in the room. The laboratories accessed in the realisation of this project have then also become constitutive environments in defining the presentation of the work in the gallery.

The video of the X-ray assay is presented in exhibition alongside appropriated footage from the investigation of the Fukushima Daiichi nuclear reactor (see portfolio pp.50-51). The footage chosen is edited from handful of videos uploaded by TEPCO (Tokyo Electric Power Company), documenting the internal investigation of the primary containment vessel of Unit 2 using a radiation-shielded endoscopic camera. The video is largely abstract, but is flecked with noise produced by the camera's sensitivity to radiation; for brief periods these artefacts overwhelm the visual image. The rationale for including this footage was to provide a real-world parallel to the assays conducted in the lab. Due to the relatively short durations of exposure possible in the X-ray assay, none of the sensors were permanently damaged. This lack of representational failure leaves the video feeling overly clinical and scientific: nothing is risked. Pairing these images places the control maintained on laboratory radiation in relief against an environmental catastrophe on the scale of Fukushima. Furthermore it is contexts such as Fukushima that the extensive photonic sensitivity of image sensors has real political consequences. This footage has direct parallels with the aerial film shot by Vladimir Shevchenko over Chernobyl in 1986 in which, as Schuppli writes, "the disaster had inscribed itself directly into the emulsive layer of the film as decaying radioactive particles transgressed the exterior casing of the movie camera" (2016: 155). In both instances, it is photographic media that have registered the extreme photonics radiating at these sites.

The form of Chapter 2 is not straightforward and requires some meta-commentary here. It opens with three short texts describing the assays in a tone which varies between laconic and poetic. These texts are more creative than academic, and should be considered part of the practice – to be printed and made available to the gallery audience to accompany the exhibition. They are written from my first person perspective and within them I have allowed myself the liberties of prose: allusion without citation, poetic description, speculation and rhetoric. For example, my scientist collaborators Dr Ben Mills and Neil Sessions are referred to conversationally by their first names. These pieces of writing are intended to contextualise the predominantly abstract video produced, giving the audience some sense of the experience of the works' production. The descriptions therefore address the laboratory environments and the process of making the work more than the videos themselves. This textual emphasis on process is intended to balance the primarily visual, aesthetic experience of watching the videos. Due to the experimental nature of the assays, I have had little control over the appearance of the videos and as the project developed, they seemed more and more like documentation of events that occur in the labs. These texts therefore help to foreground the performative nature of the practice. The site of these works is not the gallery, but the research institutes and laboratories in which they were executed, to the extent that I even (unsuccessfully) sought permission to exhibit the videos within these spaces.

These three texts are annotated with endnotes that outweigh them, and are printed on A3 foldouts to make cross-referencing more straightforward for the reader (that said, I would encourage reading the chapter in the order that it is printed – at least in the first instance). The combination of these texts with the more traditional academic commentary found in the notes results in an essay that stylistically falls somewhere between Art Writing and Science & Technology Studies. The form of this chapter is intended to make manifest the messy and non-linear relationships between practice and theory, a means of capturing what Law refers to as "the relative messiness of practice" (2004: 18). The structure used – endnotes – is in itself an academic methodology of referencing, but one which has also been used creatively as a means of speaking in two parallel voices as for example in J G Ballard's *Atrocity Exhibition* (1993). As a result of this structure, the theoretical ideas found in the notes are not laid out in a rational order, but follow the order in which they occur in the texts above. This enables the construction of a network of ideas whose inter-relationships are simultaneous rather than successive. Some of these ideas are outliers, they exist independently and in the context of an essay would seem tangential; others are so pervasive that their connections to the assays are not limited to the specific juncture of the annotation. I have diagrammed this network of ideas and my understanding of their relation to the assays in fig. 8 below. In spite of this structure, by the end of the chapter several distinct threads have been brought to conclusions, and where they are not this is largely because they are ideas which are discussed in more detail in the subsequent chapters.

The indulgence of this chapter is to afford some genuine privilege to the practice in how it is written, to try to develop a way of *writing the work* rather than writing *about* the work, one which does not force it into forming a linear argument which it itself does not make, and to which, as I have argued here, it is structurally and methodologically dissimilar. This is not a reticence on my part to engage in academic writing, but rather an attempt to find a form that is appropriate to the nature of the practice as an open inquiry.

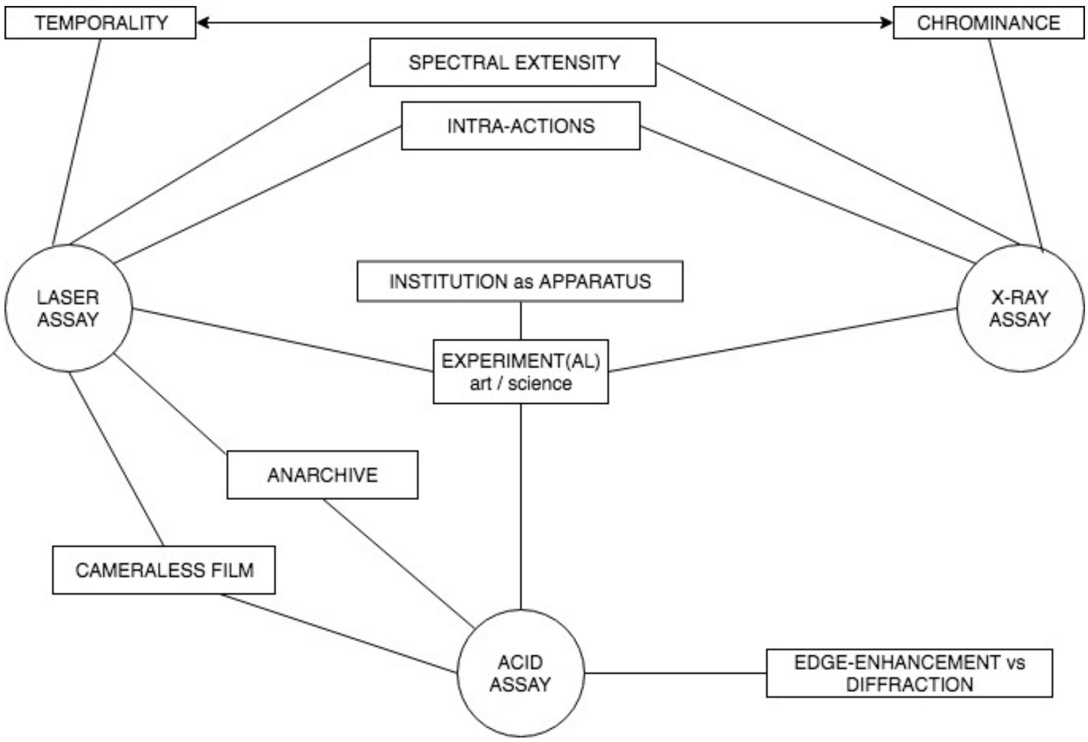


Fig. 8 Diagram of the ideas covered in Chapter 2

Chapter 2

Three Assays

Laser Assay

The laser permeates the whole lab. It is not a discrete object or machine, but moves through machines and between objects. It passes, uncontained and invisible, between Ben's keyboard and screen. It is not only an invisible wavelength but its path through the lab is hard to discern to my untrained eye. It snakes its way through lenses mounted in the regular grid of threaded holes covering the workbench. The apparatus exceeds the room in which we sit: the laser originates next door. Optical parametric amplifiers, difference frequency generators, second and third harmonic generators. Equipment for its control and manipulation extends wall to wall and ceiling to floor. The lab is a bricolage of technical media. It combines consumer technologies and specialist science apparatus, the interaction of these domains is often improvised. The environment of the lab is ordered entirely around the requirements of the laser; the steel optical table sits on a two tonne oil-bed to prevent vibration: camera shake eliminated by sheer ballast. Electrical control gear is racked overhead. We move within this apparatus,[1] surrounded and restricted by the equipment's dominance of the space.

My second hand ten mega-pixel compact camera is mounted on a stage with stepper-motor controlled micron-accurate movements in three dimensions. The conflicting economies of research science and creative practice bolted together on a 6mm thread. The camera moves beneath the laser, which, in spite of its mobility within and through the lab, has a fixed focal point. The camera is controlled spatially, the laser temporally. Their intra-action produces the phenomena encoded as video.[2]

Distances and frequencies are worked out on the whiteboard. We use arbitrarily round numbers. The photosensitive area of the sensor has a width of six millimetres, the total pan time is set at sixty seconds, this gives us a speed of one hundred microns per second. Each pixel is estimated to be five microns square. A rate of ten pulses per second would theoretically break every second column on the array. A laser system capable of flickering 1000 times a second is slowed to less than half the rate of cinema.[3] Pixel death just ten times a second. The power of the laser is modulated with Neutral Density filters, a system designed for controlling photographic exposure. If digitality has eliminated the risk of exposure from the photographic then here that risk is very much present again. We wear safety goggles.

Visibility in the lab is on the side of the scientist. The laser's perspective is reproduced on screen through the same lens that focuses the laser onto the experiment.[4] Science invariably looks down. Placing a camera beneath the lens offers us a perspective back into the apparatus, a view up from the bench. A small adjustable spotlight usually floods the experiment with light, enabling its operator to watch the damage. This dazzles the camera, we switch it off, Ben's screen goes dark. We watch the experiments from beneath, gazing up into the beam. The sightlines in the lab have been inverted, Ben is disturbed by this. One square centimeter of mass-produced photosensitive silicon gazes through a state of the art hardware system assembled above, to blind it. A rectangular machine eye images the flickering aperture of machining optics. We watch it visibly dilate and contract between passes.

The laser inscribes a line across the centre of the image. A horizon in a depthless landscape whose sun is perpetually half-set. A single white zip across a field of infrared: light cutting through silicon. As columns are broken clean white lines fracture the image vertically. Some appear to cast shadows to their right as the camera tries to build an image from the damage. It hallucinates a haze of granular noise in the empty space, sodium streetlights illuminating a codec cloud. Enigmatic artifacts begin to appear in the intra-action between micro-temporal laser pulses and the clocking rate of the sensor.[5] Horizontal bands jitter beneath the horizon, a lozenge of saturated white flutters beneath the strafing lens, rising in staccato phase[6] to the steady horizontal glide of the laser. Pulses of infrared so brief that the sensor struggles to place them in its temporal matrix.[7]

The density of broken columns increases, a venetian blind drawn slowly across the frame, the panning lens still visible behind it. The sensor's physical layers are inverted: what remains of the optical image above it appears shrouded beneath the vertical channels of its microelectronic substrate. We see as though from the back - through the whole chip. As the damage increases a gridded area is revealed beneath the horizon, electronic etchings of cyan, yellow, violet. Single pulses switch the colour space of the whole image, jerking us between a lurid artificial evening, night, and dawn.

We switch the lights back on and pan camera beneath camera, a satellite over silicon. Microlens debris is scattered evenly across the surface, a pattern of regular craters. The physical consequences of optical over-exposure, photonic excess.

Acid assay

The Integrated Clean Room facility is a space insulated and isolated from the dust, dirt and mess of the world. It reproduces within itself the conditions of digital technologies, sealed and equipped with systems for the exclusion and evacuation of contaminants.[8] Its floor is punctured with a regular grid of holes opening onto an empty cavity beneath, into which all dust falls. Around its perimeter a walkway acts as a clinical cloister allowing the work within to be observed and for limited communication between outside and inside. A thermostat maintains a constant temperature day and night. High-efficiency particulate air filtered ventilation and extraction: a system of total environmental control.

Within the clean room, the acid etching wet bench comprises another similar system. It isolates itself from the room in which it stands, diluting and containing toxicity.[9] Laminar air flow and deionised water supply maintain its distinction from its environment. The grid of holes in the floor is mirrored in the bench to drain spillage. The experiments take place here; on an environmentally controlled tabletop within an environmentally controlled room, all behind access controlled card locks.

The gowning room is the interface with the outdoor world, a space of strict protocols in which the human is treated as matter to be contained. The work is protected from our corporeality just as we are protected from its corrosion. All objects passing through are wiped down with a waxed cloth. No cardboard boxes are allowed: a clear plastic tub is provided. Shoes are wrapped in overshoes while stepping over the metal threshold, then double wrapped in over-boots. Facemask, hood, coverall, safety glasses, nitrile gloves: all bodily borders are doubly reinforced.[10] Regular users grow accustomed to recognising one another by gait and glasses. Once inside Neil dons a further layer of overgarments: plastic full-facemask, elbow-length thick rubber gloves, ankle-length wraparound apron.

The chemical composition of hydrofluoric acid necessitates all of these precautions, but to the video signal coming from the sensor its liquidity is more of a problem. Neil places a full drop from the pipette, flooding the surface and instantly shorting the signal. The image cuts to black. The substrate bubbles and smokes for several minutes. The clean room functions by establishing and maintaining barriers: between outside and inside, between volumes of air within the lab, between body and experiment. But the boundary between the electrons in the sensor's substrate and the video flow in the surrounding single strand gold wires is unenforceable.

We now work with minute quantities, much smaller than Neil is accustomed to. He develops a technique for dabbing the smallest drop onto the sensor's surface. Facing upwards inside the wet bench it focuses on nothing but is sensitive to all light in the 180 degree hemisphere above. It flickers, adjusting to shadows cast by our movement. My dated portable tripod holding the camera horizontal is incongruous among clean plastic sterility. Success at the third attempt: bubbles appear within the droplet and slowly swell. The drop of acid shifts through colours like a rapid bruise. Speckles of pink rise to the surface before darkening through purple towards black. We watch the image fracture vertically with clean white lines, before a hallucinated rainbow[11] collapses through the bottom of the frame.

I return with a larger camera. After months of scrutinising the technical specifications of various sensors its physical dimensions have become the defining factor. The physics governing the shrinkage of semiconductors are under constant revision but a drop of liquid can only be so small.

We watch damage relayed to the camera's screen.[12] Gentle ripples in the sensor's strata are rendered radiant. A machine-pupil scorched white by fuming nitric. Acid refractions of blue and orange around its dilating purple iris.[13] A matrix of rectilinear cells emerges as pixels crumble. Green and magenta channels run respectively north–south to a perpendicular black. Is chrominance extracted vertically and luminance horizontally? Seduced by the visual representation, Neil almost dabs acid onto the screen. The liquid seepage eventually reaches the signal strands. A brief, familiar monochrome flicker... ***THE MOVIE COULD NOT BE SAVED***

X-ray assay

The Faxitron MultiRad 350 weighs in at 1500kgs. A large grey cabinet on wheels with a Microsoft Windows operating system, touch screen control panel, USB and ethernet ports. Imposing, it stands like a luxury fridge in a small, square basement room. Do all non-portable media aspire to the condition of domestic white goods? From a ubiquitous computational infrastructure its single purpose is to deliver dose-accurate X-ray radiation for immunology research. The cumulative effects of hours of exposure to radioactive isotopes can now be cut down to a few hundred seconds in its beam. Dosage is controlled by the parameters of voltage, current and distance from the source: Sieverts per hour can be calculated from kilovolts, milliamps and centimetres. Electricity is the root cause of all phenomena.

The room in which it stands is a remnant of a riskier experimental process, built to contain the radiation from Caesium 137, a fission product of an alkali metal. Equipped with two generations of now inactive CCTV cameras, hazard lights, emergency procedure notices and a leaden sliding door - mechanised due to its weight. Yellowed paint and general disrepair belie its outdated purpose, the cladding has been torn away around the door to squeeze the new machine through, revealing walls laminated with an 8mm sheet of lead between plywood. The MultiRad 350 ***FOR ALL YOUR IMAGING AND IRRADIATION NEEDS*** internalises all of this within itself, folding the features of a small laboratory inside its housing. Architecture into media: a lead-lined cabinet in a lead-lined room. A doubled leaden shroud to conceal an invisible light that sees so much it burns.

Inside the machine's brushed stainless steel enclosure, a circular platform marked with the concentric rings of a target can be raised into and lowered out of the conical beam. Various thicknesses of aluminium are used as filters. The camera is perched over the centre, clad in lead: one heavy metal shielding rare earth metal circuitry from a radioactive isotope of an alkali metal. Science rearranges these elements to produce, modulate, measure, and then deplete radiation. Immunologists place white blood cells among these techno-mineral strata[14], simulating bodily immersion. I introduce a further metal, an optical silicon semiconductor. Minerals are the root cause of all phenomena.

Blocking the integral dosimeter, the image sensor becomes its surrogate, visualising the intensity of radiation as a noise pattern. Sub-chromatic wavelengths rendered as saturated reds and blues. Might alpha, beta and gamma correlate with R, G and B?[15] Radiation – photons – electrons – noise: all equated as specks of colour in the camera. Background noise is measured with respect to the signal, background radiation in millisieverts annually, they become indistinguishable in the machine eye. The noise within the system and the noise of the solar system both image as dappled colour-fields.[16] Is the difference between the contingent electrons in our technologies and the contingent signals in our galaxy merely one of scale? Radiation is the root cause of all phenomena.[17]

Notes

1.

The artistic research described above could not take place outside of an institutional environment. Technology may have become more distributed from industry to the individual, but it is hard to imagine how this might take place with the laboratory practices described here. It seems unlikely that the fab-labs of the future will have clean rooms, laser machining or irradiation facilties. My enquiry into the nature of the image sensor as a photographic apparatus is made possible by an institutional apparatus that far exceeds the camera and myself. Karen Barad has addressed this question of the extent of an experimental apparatus:

> If a computer interface is hooked up to a given instrument, is the computer part of the apparatus? Is the printer attached to the computer part of the apparatus? Is the paper that is fed into the printer? Is the person who feeds the paper? How about the person who reads the marks on the paper? How about the community of scientists who judge the significance of the experiment and indicate their support or lack of support for future funding? What precisely constitutes the limits of the apparatus that gives meaning to certain concepts at the exclusion of others? (Barad 2007: 199)

Reframing her questions in the context of *Saturation Trails* leads us to consider not just the interconnected equipment within the laboratory as a holistic apparatus but the FAST Lab and Clean Room's existence within a research unit which attracts considerable funding and can therefore afford to devote time to "continuing the quest for lateral, non-linear ideas" (ORC website). We might also look to Winchester School of Art's merger with a University whose primary focus is science and engineering as a key component of the apparatus that enabled the collaborations at the heart of this research project. Barad's expansive conception of the research apparatus has some confluence with Gilbert Simondon's concept of the technical ensemble, of which he offers the laboratory as a higher-level example. However, unlike Barad, Simondon distinguishes the bounds of the ensemble from its milieu, so for him, the funding environment would be part of the laboratory's milieu rather than part of the ensemble itself.

Combining Barad's expanded definition of the apparatus with Simondon's definition of the technical ensemble, we can conceptualise the meeting of my Panasonic Lumix compact camera and the Coherent Mira laser oscillator as a hinge between the apparatus of optoelectronic research and the technical ensemble of the consumer camera. The laser assay then provides an instance of feedback between these two mutually reliant domains. The image sensor, whose uptake as a consumer device relies on its claim to objectivity garnered through its use in research science, is pointed back at the apparatus that made it possible.

2.

Throughout these three assays, image sensors are not so much subjected to specific experiments, as they are placed inside of laboratory apparatuses, with(in) which they intra-act. Barad coins the term *intra-action* to distinguish from notions of interaction in which there are two separable agencies: that of observer and object observed. Conversely, for Barad:

> Phenomena do not merely mark the epistemological inseparability of observer and observed, or the results of measurements; rather phenomena are the ontological inseparability of agentially intra-acting components (2007: 33)

The placement of an observing machine-eye as the subject of each assay conflates observer and observed within a homogenous image-surface. The reflection of the laser's objective lens in the glass above the sensor (achieved by switching off the overhead lighting in the lab, save a single desklamp) produces a lens-less image of the laser panning left and right across the sensor (see portfolio pp.12-15). Similarly, the surface tension of a drop of hydrofluoric acid on a sensor refracts the ambient light onto the surface beneath in exactly the same way as if imaged from above, so that what is actually a dioptric (refracted) image appears to us to be catoptric (reflected): a photogram masquerading as a photograph (see portfolio pp.28-9, top row). These superimpositions of cause and effect lead to a productive confusion about what is observing what, a possible exception to Barad's rule that "it is not possible for the apparatus to simultaneously be both measured object and measuring instrument" (2007: 161). Conducting experiments that over-expose the technical architecture of a camera concomitantly exposes the instruments, materials and processes of optoelectronic science to its observation of them. The visual inseparability of cause and effect in the screen-image visualises their agential inseparability, their mutual production of the phenomena encoded into the camera's memory.

3.

In experimental film practice, often referred to as 'expanded cinema', the rejection of normative optical exposure is now an established, even traditional, methodology usually referred to by practitioners as *cameraless film* and includes techniques such as painting, scratching, and chemical manipulations of the emulsion, such as those of Stan Brakhage (2003) and more recently Hangjun Lee (2008). Akira Lippit theorises such practices as an *exergue*[*] of cinema: "outside the essential body of the work, and yet part of it", "a resistance to – but also a symptom of – the film industry" (2012: 1, 5). These practices take advantage of the intrinsic separability of the medium from the apparatus, they exist outside of but in relation to cinema and are produced literally

[*] Exergue (noun): a small space or inscription below the principal emblem on a coin or medal, usually on the reverse side (OED)

outside of and without the camera, but, through their projection, are returned to the screen and to the logic of the moving image as an imperceptible sequence of stills.

The most obvious subversion of cameraless film is its negation of the representational image, but it also subverts the temporality by which the illusion of movement is constructed. Removed from the camera the discrete frames of the movie vanish and the open flow of the filmstrip takes precedence. Although the projector mechanically reinstates the fragmentation of the filmstrip into discrete images, no two are alike. The absence of camera and lens radically destabilises the experience of illusory motion that defines the cinematic medium. Temporal experience is instead defined by the physical relationship between the length of the filmstrip and the duration of the film. We experience time not as a screen-simulation of perceptual time, but as a media-technical unspooling of the relationship between time and space: seconds wound into feet. In foregrounding the materiality of celluloid as a spooled transparent surface we no longer experience the movement of the image but the movement of the medium through the apparatus.

The relationship between material and perceptual temporalities in the digital camera could not be more different. The medium and apparatus are no longer separable entities, the medium exists only as a series of technical specifications of resolution, colour gamut, refresh rate and so on. Photosensitivity, rather than existing as a momentary chemical attribute of the medium, is embedded as a permanent attribute of the apparatus. When the sensor is removed from behind the lens, digital video becomes radically *static*, even dramatic movements of the sensor register only as subtle changes in light. They are less videos than what Victor Burgin describes as "photographs that move" (Bishop & Cubitt 2013: 201). In their stability, the component videos of *Saturation Trails* are the antithesis of direct animation on celluloid, but in both cases what we experience as a viewer is the spatial condition of the medium in question.

The fixity of the sensor within the camera precludes the video works of *Saturation Trails* from being defined as camera*less* even where they are entirely non-optical or lens-less. In some sense they might even be considered *more* a product of the camera than a traditional photograph, which is also produced by objects whose image is reflected into the camera. Even the rapidly fluctuating background noise seen in the laser assay is produced in-camera, as the image-processing algorithms attempt to normalise damage into image by resolving it in terms of overall brightness, contrast and colour. If experimental film is an exergue of cinema, then these assays are an exergue of digital photography. They exist beyond the margins of photographic practice but within the body of the camera. The videos produced are images ostensibly without subjects but are nevertheless constituted by the interior logic and materiality of the digital image itself.

4.

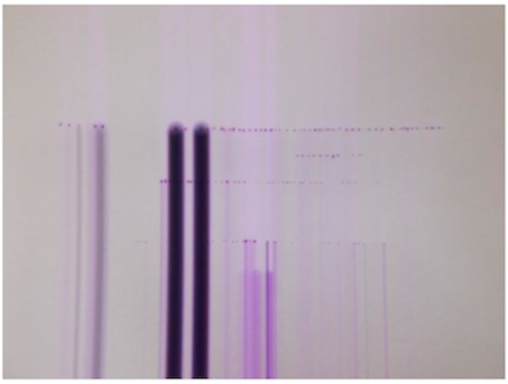
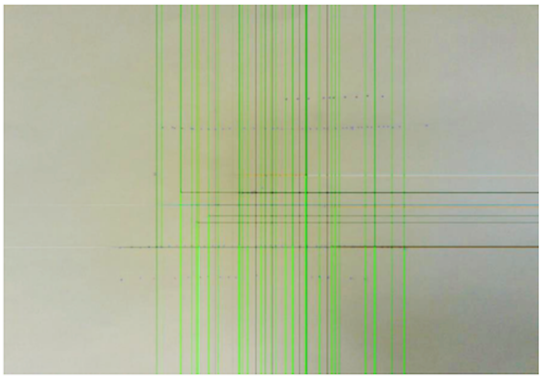
Saturation Trails comprises three experiments. Their status as experiments draws on both a history of experimentalism in the arts and an appropriation of scientific facilities and processes. I consider them experimental in the strict sense of the term, on which John Cage and Hans-Jorg Rheinberger concur. For Cage, experimental music consists of "an act of which the outcome is unknown" (1973: 13), while for Rheinberger:

> the research experiment is setup to reveal something, about which one doesn't have an exact preconceived notion, but without having at least a vague conception of something, one, on the other hand, cannot be surprised by something novel (2012)

The broad context of this project therefore draws on a commonality identified by Rheinberger between the arts and scientific research in that "both fields … deal with forms of forward facing open exploration of the world" (2012). These assays were thus conceived of as an indeterminate inquiry into the physical materiality of one of the most pivotal and ubiquitous components of digitisation.

Although experimentation aimed at intentionally provoking machine malfunctions is common in the arts, as for example in the history of audio malpractice sketched in Caleb Kelly's *Cracked Media* (2009), they are also important to science and technology as a means of establishing the damage thresholds of new materials. It was from scientific experiments designed to test the resilience of optoelectronic components that my preconceived notions about what might occur were drawn. While I have found no previous examples of image sensors being exposed to acid, radiation testing has been routine throughout the development of image sensors due to their importance in space telescopy. The laser assay, however, was almost identical to one conducted by Sacha Casken as his MSc thesis (2014). What then is the difference between conducting this as a scientific experiment or as artistic research?

The most obvious answer to this question revolves around their outputs. Casken's conclusion is focused on a quantitative analysis of the experiment. He compares results from different sensors, CCD and CMOS and between different wavelengths of laser. He also presupposes categories of damage and fits his results into those categories. Whereas most contemporary optoelectronic papers would not include the images of this damage, perhaps due to what Galison describes as "logic physicists epistemic commitment to eliminating the visual" (1997: 40), Casken thankfully does (figs. 9 & 10). However, for him the images have no intrinsic value except as data. In my experiment the image itself is the outcome and it does not serve to prove a hypothesis nor illustrate a theory. It is also not still images which are produced, but a moving image of the

Figs. 9 & 10: Images of laser damage in a CCD and CMOS sensor from Casken's MSc thesis.

entire experiment, and as such contains a lot of information which would be considered extraneous in the context of science. In science then "the process of producing the traces melts into the background … the materiality of the process gets deleted" (Law 2004: 20), whereas for me it is the materiality rather than the explanation of the phenomena that holds value. The damage thresholds which Casken sought to define have no value to me, and conversely, the incidental horizontal noise, which from my perspective remains the most beguiling aspect of these videos, would have no value in Casken's experiment. This noise equates to what Law describes as "elusive and transitory substances" that, in science, "come to be known as artefacts and are disregarded" (2004: 20).

The near identical nature of these two experiments recalls Gustav Metzger's description of his 1968 laboratory residency in Swansea as "a purely scientific construction for purely artistic purposes" (cited in Fisher 2014: 35), a description which serves aptly for all of the *Saturation Trails* assays. At times the scientific and artistic perspective on the same phenomenon are even in direct opposition to one another. Casken describes one of his cameras developing a fault, causing him to remove it from the experiment, presumably because it raises doubt about its objectivity. In the *Saturation Trails* videos, it is exactly these faults that shift the resulting videos away from the evidential and illustrative nature of the scientific image. It is the failure of the camera's objectivity that produces the work, in fact the assays comprising *Saturation Trails* were intentionally designed to erode that objectivity and reciprocally reveal what Simondon would call the sensor's technical individuality.

5.

If these assays comprise intra-actions between the interior logic of the camera and the apparatus of the lab, then in the laser assay these intra-actions are primarily temporal. The laser flashes at a pulse rate of just 10Hz, well within our perceptual reach, but each pulse is so short (150 femtoseconds) as to be imperceptible to the naked eye (were an 800nm wavelength even visible). Similarly, while the camera outputs video at a 25Hz frame rate specifically targeted to human vision, its sensor is clocked in the megahertz range. Both the apparatus of the laboratory and the ensemble of the camera therefore operate outside the threshold of human temporal resolution, just as does our photonic environment.

> Forms of time implemented in the real … long remained undiscovered … because they were hardly measurable with human senses and mechanical instruments; Leibniz anticipated their discovery as *petites perceptions*. When light shined it appeared as a pure emanation and not as a vibration in the electromagnetic spectrum. (Ernst 2016: 6)

The electronic instruments of research science, and the consumer products which have trickled down from them, now offer mediated access to these imperceptible frequencies and embed such micro-temporalities within their own architecture. If a camera can readout 60 million pixels a second, then it can also re-write those pixels at the same speed. To the 'petites perceptions' of vibrating light we can now add a range of machinic rhythms that combine to model our perception. The camera intervenes between the hundred-trillion-Hertz frequencies of visible light and our tens of Hertz perceptual limits by implementing a mediating time-scale of several-million-Hertz: it slows down the passage of light-time in order to capture and re-present it as a recorded image. As Blom writes of video recording: "storage is best defined as a temporary slowing down of events" (2016: 106).

For Ernst "the perception of time is coupled with the act of measuring time and measuring media" (2016: 37). If, as he suggests, temporal experience is as defined by the medialogical intervention of devices for its measurement as it is by our bodily experience of time, then what is the effect on our perception of lived time when those media reach a temporal resolution so alien to our own nervous impulses?

6.

Simondon understands the relation between such distinct temporalities as a system of phases:

> This sense of the word phase is inspired by the notion of a phase ratio in physics; one cannot conceive of a phase except in relation to another or to several other phases; in a system of phases there is a relation of equilibrium and of reciprocal tensions; it is the actual system of all phases taken together that is the complete reality. (Simondon 2017: 173)

We can now see the distinct temporalities discussed above as existing in a series of phase ratios with one another, the pulse length of the laser exists in phase with the sensor's clock rate and the pulse rate with the camera's frame rate. Our perceptual reality is mediated in a complex system of phases between photonic time, perceptual time and electronic clock time. The intervention of the latter between the former two results in a phase shift in phenomenological experience from one defined by bodily temporality of nervous impulses to one mediated and pre-constructed by machinic temporalities beyond our perception. As Crary writes, "what once might have been called reverie now most often takes place aligned with preset rhythms, images, speeds and circuits" (2001: 78)

7.

We could then conceive of the image sensor as a tempo-chromatic transducer: its input is temporal and its output chromatic. At its pixels it collects photons of different frequencies and transduces them into colours. Crucially for the assays carried out in this project, this function is not restricted to *visible* colours. The sensitivity of CCDs to extra-visual portions of the electromagnetic spectrum was a defining factor in their early uptake for military and space telescopy applications. A CCD sensor is usually *more* sensitive in the infrared range than the visible spectrum. This proved crucial during the early development of CCD sensors in securing support and investment from planetary scientists and the US military's Night Vision Laboratory (Smith & Tatarewicz 1985). As Carolyn Kane writes:

> Both ultraviolet and infrared are synthetic colours whose very existence foregrounds the centrality of machines and information systems in modern perception. In order to analyze infrared it is therefore necessary to wrest traditional notions of colour from anthropocentric theories of vision. (2014: 218)

In consumer cameras these wavelengths are filtered out, a practice that, as I discuss at length in Chapter 3, can be understood as a reassertion of the dominance of anthropocentric vision. In this shift from military and scientific applications to consumer use we can see a power dynamic in which the extra-visual portions of the electromagnetic spectrum are reserved for technologies of control and knowledge production, while only the visible spectrum is disseminated to consumers. The rendering of invisible infrared and X-ray wavelengths as visible colours in *Saturation Trails* therefore questions the chromatic nature of the digital image.

8.

We could see the conditions required in the Clean Room through the Simondonian lens of the technical object's *associated milieu*. In his discussion of the genesis of technical objects, Simondon writes:

> This object needed a regulative external milieu in the beginning, the laboratory, workshop or sometimes the factory; it gradually increases its concretisation … the object

> frees itself from the originally associated laboratory and dynamically incorporates the laboratory into itself through the play of its functions. (2017: 50)

For Simondon then, the digital camera reproduces within itself the conditions of the clean room in which it was manufactured. From this perspective we can relate details of the camera's construction to the architecture of the laboratory, noting how the sealed units common to all digital electronics seek to maintain the clean room conditions of their manufacture. The sachet of silica gel wedged into the corner of hard drive discs operates as a dehumidifier, the ultrasonic vibration of a camera's sensor-cleaning mechanism acts as a dust extraction system. The Clean Room isolates technology from the dust of corpo-reality and the technologies produced in this environment must maintain this isolation when they leave the lab.

9.
The acid etching wet bench is an isolating system nested within the isolating apparatus of the clean room. The sensor too exists within a separate regulative milieu nested inside the camera ensemble, a milieu that comprises both atmospheric and technical conditions. It is sealed behind glass to exclude dust and moisture and supplied with specific voltages and frequencies to ensure its consistent functioning. In this nesting of the sensor within camera we therefore see a replication of the regulative milieus of wet bench and clean room. A consumer system for the control of light mirrors a laboratory system for the control of acid.

10.
Just as Barad questions the extent of the apparatus she also questions the received wisdom about what constitutes the edge of our own bodies. She cites Richard Feynman, saying:

> The fact that there is an enhancement of contours [in human visual perception] has long been known … How used are we to looking at pictures that have only the outline! What is the outline? The outline is only the difference between light and dark or one colour and another. It is not something definite (2007: 156).

The outline then is produced in visual cognition and digital cameras externalise this physiological predisposition in various elements of their own technicity. The auto-focus function operates by mathematically finding the highest contrast contours within the image and rendering these edges as sharp as possible, a process which is then repeated by the camera's edge enhancement algorithm in what amounts to a mathematisation of our sensory physiology.

Conversely, the gowning practices associated with clean rooms implicitly acknowledge the inherent ambiguity of our bodily borders: shrouding our bodies in coverall, facemask, gloves and glasses draws an outline around us, isolating us from our environment. As Barad writes: "when it comes to the 'interface' between a coffee mug and a hand, it is not that x number of atoms belong to the hand and y number of atoms belong to the mug" (2007: 156). The containment of the body experienced in clean rooms serves to reinforce an otherwise ambiguous boundary between our skin and the lab, to enhance our edges.

11.

In both the laser and acid assays there are chromatic artifacts which appear to be produced within the sensor, colours created by the erosion of the sensor's substrate which have no photonic referent: machine hallucinations (see portfolio p.15, bottom row & p.27, bottom row). As Kane emphasizes, even in a representational digital image, "the colours seen on screen do not actually exist in the screen, or fixed in the electronic signal" (2014: 67) but are themselves perceptual aggregates produced by the additive mixing of three primaries. This collapse of even an ostensibly indexical chrominance serves as a reminder of the thoroughly algorithmic nature of digital colour. Just as the CCD itself is the product not of photographic but computational research, electronic colour too is, according to Kane, "the legacy of technical computing, not in the history of optical media" (2014: 75). If psychedelic experience reveals (greek: deloun – to make visible) the mind (psyche) to itself, then we might frame these assays as chromatically *techne*-delic: revealing the thoroughly technical nature of the digital production of colour to their viewer.

12.

These assays actively seek to force the transparency of the image sensor's reproduction to falter, as a means of revealing its true operation and materiality. This approach follows the media theoretical truism noted by Ernst (among others) that: "only at a moment of technological breakdown will the medium become visible" (2013: 48). In digital technologies this moment of malfunction is more powerful than in their analogue predecessors. In analogue media the substrate mingles perceptibly with representation: signal and noise coalesce, but digital media are premised upon the imperceptibility of their encoding, their physicality shrouded behind a false ideology of immateriality. The moments of fracture in *Saturation Trails* act as a rebuke to this ideology. As Matthew Fuller writes of John Hilliard's *A Camera Recording Its Own Condition*:

> what is productive about this set of images is that it articulates the camera as the possessor of compositional drive – form is generated by the material qualities of the camera … Mobilising that potential disturbance of and within the nested and antagonistic programs of media now comes sliding into opportunity. (2005: 84)

In digital images (and throughout *Saturation Trails*) the material form of the sensor doesn't so much frame or surround it as undergird it: a substructure that maintains an illusory surface. The broken columns exposed by the application of lasers and acid are the blueprint for all images, the schematic by which our photonic environment is mapped as a picture plane. If, as Azoulay writes, "the camera is an opaque tool that does not expose anything of its inner workings" (2012: 16), then opening this camera exposes the sensor both to unrefracted light and to our sight, while the application of laser, acid or X-rays moves one step further: disclosing the invisible constructions within the image itself. The history of X-rays as a medical technology for photographing interior space is tied to precisely this function of imaging the invisible, revealing that which lies beneath the surface. For Lippit, the X-ray was "a new form of light that yielded a new visuality … one that explicitly recorded the destruction of its object, producing at once an optics and an archive of annihilation" (2005: 5). One of the primary concerns of *Saturation Trails* is precisely to record the destruction of image sensors, but from their own perspective rather than externally: an auto-archive of annihilation.

13.
The project follows what Derrida, and Zylinska (2017: 188), both refer to as an *anarchivic* impulse: "aiming to ruin the archive as accumulation and capitalisation of memory on some substrate" (Derrida 1995: 12). The greatest threat to this aim lies in the almost instantaneous ability of the digital image to appropriate all subjects back into its own commodity logic. Derrida describes this ability as "the inexhaustible economistic resource of an archive which capitalises everything, even that which ruins or radically contests its power" (1995: 13). That risk is most apparent in the undeniable aesthetic appeal of the liquid photograms produced in the acid assays (see portfolio p.31, second row). The actions performed in *Saturation Trails* are of no value to me as artworks if they are not recorded, yet it is exactly the ability of the digital image to valorise the visual which, in exposing, they seek to contest. In these specific instances the action is not only archived but doubly archived: the destruction of each sensor being recorded from the camera's own perspective and from an external, documentary position; proliferating multiple images from a singular event. No matter how potentially militant the action of vandalising a camera with a drop of acid, it remains a protest trapped in the same logic of archiving and dissemination as that of networked-image-commodity against which it stands. As Matteo Pasquinelli writes: "resistance against the capitalism of the spectacle is hard, precisely because there is no room for the negation of visibility" (2008: 150).

In this instance, visibility is negated only in the cut to black that terminates the vast majority of the videos produced from this project. Ultimately this cut fails to depict what is actually occurring, not only because the object of scrutiny is no longer visible, but because it is a cut for which we are already prepared as the universal signifier of cinematic closure: cut to black, roll credits. The failure of the image sensor is in no way differentiated from the end of the movie. The disposability of hardware mimics the disposability of culture. The movie ends, we switch over; the camera breaks, we buy another. The actions performed in *Saturation Trails* remain trapped in the economic logic of cultural production, and might then be seen as an example of what Pasquinelli describes as:

> a new grammar of sabotage where this mode of sabotage is productive of value and creative, not simply destructive. Such positive sabotage is not a form of Luddism – it is impossible to destroy the machine, as we ourselves have become the machine (2008: 151).

The relationship described here by Pasquinelli between technical architectures, subjectivity and social machinisms is the subject of Chapter 4.

14.
"Media history" writes Jussi Parikka "conflates with earth history… metals and chemicals get deterritorialised from their strata and reterritorialised in machines that define our technical media culture" (2015: 35). The re-stratification of minerals within the MultiRad 350 enables an extraordinary control over the irradiative conditions of its environment. It can recreate within itself the effects of radiation exposure to environments or materials such as space or uranium. The minerals and metals of earth are reorganized to simulate the extra-terrestrial. This machine represents a mediatisation of extreme photonics: a technical implementation - and containment - of the inhospitable.

15.
What are the limits of an image sensor's chromatic objectivity? Is a CCD actually capable of distinguishing alpha, beta, and gamma radiation as different colours? It seems highly unlikely that there is any correlation between these super-chromatic wavelengths of X-ray radiation and the chromatic output of the sensor in the X-ray assay. When we watch the noise in these irradiated cameras, what is it that we are seeing? We can say confidently that this noise is produced by photons striking the sensor, and the correlation between increasing voltage and/or current and an increase in the density of the noise confirms the sensor's ability to approximately quantify this eXtremity of light. But, in the transduction of avisual light into the spectrum of colours, the agencies of the X-ray beam and the camera's operation become entangled. We observe the sensor's interpretation of an input beyond the chromatic limitations of its output as much as we do the beam itself, as Barad writes in her discussion of Niels Bohr's epistemology: "there is no unambiguous way to differentiate between the objects and the agencies of observation" (Barad 2007: 196). This assay offers a proto-typical example of Barad's theory of

intra-action in observation: is the camera revealing the X-rays to our sight or are the X-rays revealing the sensor's transduction of indeterminate photons back inside the visible spectrum? Both are true. The phenomena archived as a .mov file on the SD card is produced by the equitable intra-action of these two technical systems.

16.
The standard test for noise in a digital camera is to produce a 'dark current' exposure (see fig 24, p.87). This is done by making a long exposure in pitch black, or with the lens cap on, and reveals a speckled noise field of residual charge in the system, an image distinctly similar to the noise fields produced in the first X-ray assay (see portfolio pp.46-7). Dark current images can be used as control images to assist in the algorithmic removal of noise from long exposure photographs such as those captured by space telescopes, even though their pointillist colour fields often bears a striking similarity to much of the signal captured. In producing such astronomical images noise reduction is just one stage in the algorithmic production of a visual image from a spectrum of electromagnetic signals that far exceeds the visible. Hence, for Douglas Kahn: "contemporary astronomical images such as those produced by the Hubble Telescope, represent phenomena otherwise invisible to the human senses and are thus aesthetic exercises" (2013: 198) (for further consideration of the use of colour in astrophotography see also Kuc & Zylinska (eds.) 2016: 75-92). The process of imaging X-ray radiation used here also produces a representation of an otherwise invisible phenomenon, but one in which there is no aesthetic reconstruction of the image. If, as Kahn continues, the "conventions of scientific rendering minimise and eliminate noise as an embarrassment of the technology, rather than an engagement with existing physical forces" (2013: 199), then the assay conducted here endeavours to do the opposite, to bring the super-chromatic operation of the sensor into dialogue with the eXtreme photonics of the MultiRad.

17.
In the third text at the start of this chapter I present three possible totalizing narratives: that all phenomena can be understood as variations of voltage and current, as different arrangements of minerals, or as portions of the electromagnetic spectrum. None of these alone are true, but I do understand the three assays that comprise *Saturation Trails* as pointing to three continuities: the continuity between the voltages that power our media and those that represent their content; the continuity between the minerals from which our technologies are manufactured, and those metals that must be leached from them following obsolescence; and the continuity across our semantic divisions of the electromagnetic spectrum.

The laser and X-ray assays redeploy an instrument designed to measure the *in*tensities of light across its surface as one capable of measuring the *ex*tensity of light beyond the visible. These assays foreground the electromagnetic spectrum as a continuum extending beyond the near infrared and X-rays (which mark the scope of this investigation) and poses the image sensor as a potential mode of engaging with this spectrum. In the dizzying realisation that rays, beams and particles - only a small portion of which are sensible - are continually bombarding and passing through our bodies, might the image sensor not provide access to and comprehension of some of these phenomena?

If *Saturation Trails* has an argument, makes a point or addresses a question then it is to ask why must photography be expunged of its associated experimental practices by its digitisation? And why the camera has been deterministically limited to replicating physiological vision rather than understood as a means of engagement with light in all its extremities, and with image production processes that are not exclusively predicated on the retinal model. In Chapter 3 I discuss at length this relationship between the technical architecture of the image sensor and our own visual physiology, exposing the technics which filter, enumerate average, and exclude photonic frequencies in order to replicate and captivate human sight.

Chapter 3

Perceptual Technics for a Post-Optical Epoch

Man's relation with machines takes place at the level of the functions of transduction … but it is very difficult to construct transducers comparable to the living thing.

Gilbert Simondon

This chapter addresses the first half of my second research question: How has the image sensor reconfigured our relationship with our photonic environment? Where the artwork discussed above consists of the literal dismantling of cameras: the exploration and excavation of their sensors' operation by physical and practical means, this chapter addresses these same goals but through theoretical analysis. Achieving this requires a grasp of the technical details of the camera and therefore some reference is made to technical literature alongside media theory and philosophy of technology. While the practice is limited exclusively to working with the sensor, here I delve into the camera apparatus as a whole, notably including its screen and processing algorithms, peeling it apart into its constituent components. The chapter as a whole could therefore be analogised to an exploded diagram (fig. 11).

Fig. 11 Exploded view of a digital SLR camera

My aim here is to come to a detailed understanding of digital camera technics, with particular emphasis on their relation to our perception. I approach this as a comparison between the process of image capture and human visual physiology, elucidating how the digital image is prepared for and addressed to human perceptual limits as well as where it diverges from or exceeds them. In drawing this comparison between evolved, biological sight and devised, technological vision I consider them as equally technical systems for the production of an image. This comparison is undertaken in the same spirit as that Katherine Hayles makes "between nonconscious cognition in biological lifeforms and computational media" which is explicitly "not meant to suggest that the processes they enact are identical or even largely similar" but rather "that they perform similar functions within complex human and technical systems" (2017: 13). I do not then mean to analogise visual cognition to digital computation but rather to seek the correlations and disparities between these two distinct systems in order to understand and assess the impact of the camera on subjectivity, which is the focus of the following chapter.

Comparisons between technical instruments and sensory anatomy are commonplace in the history of media. Long before Marshall McLuhan characterised media as the extensions of man, new technologies were consistently developed in imitation of human physiology. In Jonathan Sterne's genealogy of audio technology, for example, it is the "shift from models of sound reproduction based on imitations of the mouth to models based on imitations of the ear" (2003: 33) which marks the origin of modern audio media. Sterne begins his history with Alexander Graham Bell and Clarence Blake's ear phonautograph of 1874, an inscriptive apparatus constructed around a literally excised human middle ear. He goes on to demonstrate the centrality of aural anatomy in the tympanic membrane and stylus of mechanical sound reproduction technologies.

The tympanum is the ear's transducer, the point at which physical vibrations are conveyed to the auditory nerve, or, to use less corporeal and more medial vocabulary, converted into electrical signals. A similar physiological genealogy of visual media would, no doubt, focus on the anatomical site of photonic transduction: the retina. Just as the diaphragm and voice coil of a loudspeaker imitates the ear while inverting its function: producing rather than perceiving sound, the physical construction of the retina is also found inverted throughout the history of screen media.

From the invention in 1869 of the Crookes Tube through to the Cathode Ray Tube (CRT), visual display technologies have routinely imitated the combination of retina and optic nerve found in the human eye. The signal in a CRT emits from a central cathode, projecting electrons through a vacuum-tube to strike an aluminium anode, causing the phosphor-coated screen to emit light. This transduction of signal into light inverts the action of the retina while retaining a physical structure so similar that it retains its flaws: the blind spot of human vision is echoed by a bright spot at the centre of the screen. It was not however, until the invention of the CCD in 1969 that visual media effectively reconstructed retinal photosensitivity in an electronic component. As Wolfgang Ernst has observed:

> Mechanic cinematography is… farther from human image processing than the electronic-digital. The brain processes not optical and acoustic signals as such, but rather their conversion into anaesthetic nerve impulses, which is entirely consistent with coded data processing in electronic computers. (2016: 45)

If the physical and formal resemblances between human sensory anatomy and media are at times intentional and at others incidental then the same cannot be said for the perceptual relationships between the two. The design and implementation of media hardware, formats, and standards follow lengthy periods of research which inevitably include some element of 'subjective testing': a process which attempts to quantify the perceptual effectiveness of the test object (be it a model of display, compression algorithm, or storage format) with respect to a tried and tested standard. Sterne, who has chronicled this process in considerable depth with respect to the MP3 format and NTSC colour standard, coined the term *perceptual technics* to describe "the application of perceptual research for the purposes of economising signals" (2012: 19). Sterne uses the example of AT&T's psychoacoustic research which enabled them to increase the capacity of the telephone system by filtering out frequencies which were perceptually redundant in the transmission of dialogue, essentially allowing them to "monetise the gaps in human hearing" (2012: 19).

Applying Sterne's idea of perceptual technics to the digital camera enables an understanding of its operation as being optimised with respect to the psychophysical limits of human visual perception. The compression of image and video data into JPEGs and MPEGs, as analysed by Adrian MacKenzie (2006, 2010), monetises the gaps in our vision in just the same way that AT&T, and the MP3 codec have for audio. Furthermore, if Sterne defines perceptual technics as the harnessing of all signals by economic logic, then, given the equal technicity of the physio- and techno-logical, I propose that we understand *signal* in both its media-technical and its biological senses, and that, as a consequence of the compression of audiovisual signals, human biological sensory signals become monetised.

While such technics embed perceptual limits in technologies, media are also employed to establish perceptual and subjective norms. As Jonathan Crary points out: "attention was studied in terms of response to machine-produced stimuli, often electrical in nature and abstract in content" (2001: 27). Since the pioneering psychophysiological experiments of Gustav Fechner and Hermann von Helmholtz, sensation and perception have been defined by and in relation to media technologies. As Kittler writes:

> It was only after processes of perception had been examined in such cold and inhuman fashion, as if they were technological media, that nothing stood in the way of the construction of real media that deceived and/or simulated that perception. (2006: 42).

As much as media technologies are often explicitly modelled around the perceptual faculties of their imagined user, our bodies have, over the course of 150 years or more, been modeled as and by media. Helmholtz goes as far as to write of the body as an explicit extension of the machine: "even the human arm may be moved by electricity so as to convey telegraphic signals" (Warren & Warren 1968: 84). So, long before today's media-saturated environment, McLuhan's adage of organ extension is problematised by the mutually constitutive interaction between parallel developments in perceptual science and media technology:

> What we take to be a body is already in some sense technical and therefore bodies and technologies couple in ways that are a little more complicated than any simple version of technology as organ extension suggests. (MacKenzie 2002: 20)

This mutual entanglement of media and perception suggests that we could replace the model of prosthesis, in which the human subject is posited as the inevitable centre around which media cluster with a model of perceptual intra-action. In Barad's concept of intra-action any phenomenon, in this case an image, is not captured by a camera and perceived by a human subject, but is produced in the intra-action of camera technics and human physiology. For her, these entities do not pre-exist as determinate subject or object but are constituted through, and in the moment of, their intra-action. From this perspective, not only do technologies extend our senses outwards, they also constitute our subjectivity. Hayles, arguably going a step further than Barad, uses a model of *interpenetration* in describing "biological and technological cognitions" as "so deeply entwined that it is more accurate to say they interpenetrate each other" (2017: 11). We can therefore see mediation as equally extending inwards, the human subject becoming a bio-extension of a media environment, that Jussi Parikka describes as "a milieu in which we are coordinated to perceive, move and practice cognitive functions in particular ways, in particular relations" (Fetzner & Dornberg 2015).

In what follows then, I will seek an understanding of visual perception and digital image production as equally technical processes which mutually inform, define and constitute one another, as what Barad has called "agentially intra-acting components" (2007: 33). I will examine the perceptual technics of the digital camera through its relationship with human visual perception as an intra-action of two increasingly entangled agencies, the biological and the computational.

My analysis of the camera uses two key methodological approaches, introduced in the following two sections: phenomenology and transduction. The former is based in the work of Don Ihde and Mark Hansen, the latter drawn from the ideas of Gilbert Simondon and their more recent interpretation by Adrian MacKenzie. In attempting a close reading of our 'complex couplings' with digital machine vision - primarily but not exclusively in its widespread consumer context - I hope to expose the ways in which our subjectivity is constructed in these perceptual mediations and what these specific affects reveal to us about the ideologies embedded within the camera.

Media Phenomenology

My emphasis on the relation between corporeality and technics necessitates a phenomenological understanding of mediation. To this end I draw on Don Ihde's *Phenomenology of Instrumentation*, a detailed phenomenological account of mediated perception, published in 1979 as the first part of *Technics and Praxis*. I use this as a traditional phenomenological analysis, but one which is nevertheless recent enough to draw significant and, for my purposes, relevant distinctions between, for example, a microscope and an electron microscope. Alongside Ihde, I refer to Mark Hansen's contemporary account of media technologies, which emphasises their phenomenological impact, extending the ideas of Merleau-Ponty into a contemporary digital context.

Ihde distinguishes three types of relationship between subject and instrument: *embodiment relations*, *hermeneutic relations* and *background relations*. Embodiment relations are those "in which the machine displays some kind of partial transparency in that it itself does not become objectified, but is taken into my experiencing of what is other in the world" (1979: 8). Ihde's foundational example here is the dentist's probe, possibly chosen as a more technical alternative to Merleau Ponty's example of the blind man's cane (2002: 165) and one which is understood solely as extending tactility rather than standing in for sight. Merleau Ponty calls such instruments *bodily auxilliaries* (2002: 176). For Ihde, the probe is not experienced as a distinct object but becomes an extension of the dentist's tactile sense, *amplifying* the texture of the tooth. Ihde uses the telescope and microscope as examples of visual embodiment, both of which recede into the background during use, bringing the objects of our experience respectively closer to, or larger within, our field of vision. Such technologies have a tendency to amplify what Ihde describes as a mono-dimension of perception, while necessarily and simultaneously reducing other aspects. Ihde refers to this as "the amplification-reduction structure" (1979: 21).

Hermeneutic[1] relations are those in which "there is a partial opacity between the machine and the world and thus the machine is something like a text" (1979: 12). Here then, the focal object of our experience is not the world but the machine itself, these relations include those in which the machine allows access to sensations beyond what Ihde refers to as "naked perception" (1979: 11) and his examples include the electron microscope, space probe and spectrograph. Here, there is "a more distinct discontinuity with bodily vision … one no longer looks *through* the instrument, instead a substitute 'eye' is used … yet the representation is still *of* the thing itself" (1979: 30). So, if digital photography has a tendency to reduce or even eradicate the use of an optical viewfinder and replace this with vision mediated on screen, then in these phenomenological categories, this moves our relation with the camera from the embodied towards the hermeneutic. Our experience is less often of the world as composed by the lens of the camera, but rather of the camera, replete with its internal semiological abstractions, as interpreter, or to use Ihde's terminology, 'hermeneut' of the world.

Ihde's final category, background relations, refers to those in which the human subject "may be said to be *inside* a machine", for example, "in many modern buildings in which there is a total environmental control by way of technological artifacts" (1979: 14). Since the time of Ihde's writing such relations have obviously become both more commonplace and extensive and this acceleration exerts a decisive influence on experience. For as long as the background of our experience remains predominantly non-technical, the easier it is to distinguish the amplification-reduction structure of each technological mediation. However, in a world where our background is predominantly technical, the amplifications and reductions wrought by individual technologies become indistinct. Furthermore, in the context of the early twenty-first century the extent to which the human subject may be said to live inside a machine must no longer be understood solely in the physical terms used by Ihde, but has increasingly pertinent mental and social dimensions. Of Ihde's three categories, it should already be clear that only embodiment relations can be understood with respect to McLuhan's paradigm of organ extension or Merleau-Ponty's model of the bodily auxillary. Conversely, in hermeneutic relations the technical instrument is experienced as external to and distinct from our bodies. In these two types of relation Ihde establishes "two quite different trajectories for our investigation. These may be called a trajectory towards the perceptual and a trajectory away from the perceptual" (1979: 36).

Mark Hansen also emphasises embodiment, specifically in the context of the virtual reality environments analysed in *Bodies in Code* (2006). However, where Ihde insists on the primacy of

[1] It is worth noting that throughout this chapter I use this term solely with respect to Ihde's phenomenology and without any reference to the philosophical tradition of hermeneutics.

naked perception, Hansen instead proposes "a view of the human that refuses to divorce technicity from embodiment" (2006: 99) arguing not only that "the human has always been technical" (2006: 131) but that this humanity has always existed in what he describes as a "constitutive correlation with technics" (2006: 132). Although in the course of this argument he refers to the "earliest flint chipping tools" (2006: 61) as an example of the foundational technicity of the human being, more importantly in this context he also insists on "imaging as an inherently technical originary element of the organism's being" (2006: 19). For Hansen, even in unmediated perception, experience is:

> conditioned by the transduction of embodiment with technicity… The human is and will always remain split, inhabiting the two separate, incompossible yet superposed worlds of the tactile and the visual. Only because humans are embodied beings are they able to conjoin these divergent worlds of sense: embodiment is the condition for a phenomenisation of being that emerges in the gap between vision and touch (2006: 79)

As a result, in Hansen's account, embodiment in mediation hinges less on the transparency of an instrument to our sensation than it does on a recursive correlation between tactility and visuality. He criticises mono-sensory phenomenological accounts of vision, insisting instead on "the kinaesthetic and proprioceptive dimensions of bodily self-movement … [which] serve to confer reality on perceptual experience" (2006: 125). It is important to note that the examples on which Hansen draws are almost exclusively artistic virtual and augmented reality environments and that he is also critical of "the default perspectival interface" for its tendency to "effectively erase the body from the computational system" (2006: 46). Applying his argument in the context of the digital camera, an instrument whose monocular lens reproduces this perspectival construction, has consequent limitations.

Nevertheless, comparing Ihde's and Hansen's models of embodiment in mediation leads to a more nuanced and complex picture which can be instructive where the pervasive tendency of digital screen media has been to widen the gap between vision and tactility, reducing touch to what Alessandro Ludovico, in his writing on touchscreens, has called a "functional and mostly decontextualised … vocabulary of abstracted gestures" (2016: 105). Reviewing Ihde's examples of embodiment: the telescope and microscope, from the perspective of Hansen's model, in which a recursive relation between vision and motility is a prerequisite of embodiment, leads us to consider these media as tactile as well as visual instruments. Only in the most primitive handheld telescope does the effect of our motility upon vision retain any relation with unmediated perceptual experience. Conversely, even in a rudimentary microscope, the recursion between motility and sight is mediated by an instrumental tactility: we must learn the gestures necessary to control the apparition through the lens and to move it with respect to our sight. Once this instrumental manipulation is mastered however, we might consider any technical instrument to become embodied in use, leading Hansen to describe technical embodiment as an essentially intra-active process:

> a transplantation of the body into things and incorporation of things into the body that, with each new habit and thus each new prosthesis, leaves the boundary between them less discrete. (2006: 44)

Given this confluence with Barad it is worthwhile elaborating her example of the ultrasound sonographer (2007: 204), with respect to embodiment. As ultrasound utilises an extra-visual portion of the spectrum and relies upon a learned ability to decode its visualisation, Ihde would certainly consider this to be a hermeneutic instrument. Yet there is clearly a recursive relationship between the sonographer's screen-mediated sight and the tactility and motility of her handling of the probe. From this perspective it becomes hard to see what difference there is in terms of embodiment between the probe in the hands of a sonographer and the probe in the hands of the dentist. The shortcoming of Ihde's phenomenology of technical mediation lies in its almost unquestioning presumption of the centrality, determinacy and perhaps above all impermeability of the human subject. A presumption roundly dismissed by Hansen who instead insists that "technical prosthetics might actually modify the way in which the body experiences sensation" (Hansen 2006: 128). A similar position is espoused by Barad, for whom, the subjectivity of the technician is constituted in and by her use of the ultrasound apparatus.

So, while Ihde diagrams his relational structures as follows:

embodied: (human—instrument) —> world
hermeneutic: human —> (instrument—world)

a diagram of Barad's model of intra-action in observation might look like this:

human<—>instrument<—>world

Where Ihde's categories remain useful however, is in identifying the nature of the mediation with respect to human perception. Ihde is clearly wary of the extent to which hermeneutic relations operate outside of our experience, describing "the nature of the connection between the instrument and the object (the dash between instrument—world)" as potentially becoming "extremely enigmatic, particularly because there is an *unexperienced* opacity here" (1979: 37). For Hansen, writing almost 40 years later, this opacity has become absolutely central to his understanding of mediation in the twenty-first century. Thus he describes our experience as "increasingly conditioned and impacted by processes that we have no direct experience of, no direct mode of access to and no potential awareness of" (2015: 8), leading us to a contemporary condition in which subjectivity is partially constituted by what Jonathan Beller has called "algorithmic function[s] beyond our ken" (2017a: 147). This addresses the crux of my argument here with respect to digital cameras. For even in this ostensibly simple example several distinct technicities, all of which are considerably more opaque than a lens, intervene prior to the perceptual appearance of an image. As a result, as Hansen writes, "experience can be manipulated prior to its resolution into bodily and perceptual effect" (2015: 195) and it is on these grounds that he describes twenty-first century media as "driv[ing] a wedge between the event of sensibility and … bodily or conscious experience" (2015: 194).

In this chapter then I will unravel the opacity of the distinct technical components of the digital camera and their apparent cohesion into a singular apparatus. In this analytically exploded diagram of the camera I seek to offer access to and awareness of the processes, agencies and technicities which govern contemporary image production with a particular view to their constitution of subjectivity. I will therefore account for the inherent amplifications and reductions of perceptual experience through an analysis of the camera's technics. To do so without falling into generalisations such as Hansen's 'twenty-first century media', I will divide the camera's image production process into three distinct parts, beginning with two hardware components: the image sensor and screen, before discussing the image processing algorithms which intervene between them. In breaking down the camera into these components I draw on terminology established by Gilbert Simondon in his analysis of the concretisation[2] of technical objects. If, as Adrian MacKenzie writes, "a technical mediation assembles heterogeneous elements from different times, from the paleolithic to the contemporary" (2002: 70) then the camera's mediation must be understood, not as coherent or singular, but as a sequential process achieved by a diverse collection of technical elements - both hardware and software - each of which may have distinct genealogies or operational protocols. A comprehensive understanding of the digital camera must account for these differing technicities within the whole. In Simondon's own words:

> It is absolutely necessary that each man employed at a technical task should acquaint himself with every conceivable aspect of the machine… and should pay attention as much to its elements as to its integration into the functional ensemble (1980: 96)

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2 It is important to note that in Simondon's broader philosophy, the process of concretisation is more commonly referred to as individuation, which includes both living and non-living processes. As my primary concern here is with the genesis of technical individuals I will use the former throughout.

Simondon's Technical Terminology

Simondon establishes three distinct categories of technical objects which can most often be found nested within one another. The largest of these is a *technical ensemble*, which can be used to refer to a large and complex machine or a distinct technical process and in itself contains more than one level, hence he defines higher level ensembles "(that of the factory, for example)" (1980: 72) as containing sub-ensembles. Within these ensembles he proposes two further categories of *technical individual* and *technical element*.

To bring these categories to bear on the technics of digital vision we must understand a camera as a lower level technical ensemble. The higher level ensemble within which the camera exists might be understood as the factory which produced it or at a higher level still the global infrastructure of injection moulding, electronics manufacture and mineral extraction[3]. However here I will concentrate on the sub-ensemble of the camera itself.

The digital camera is composed of several technical individuals. A quick run-through would include hardware: the lens, shutter, sensor, memory chip, screen, and battery; and software: the menu system, light meter, graphic user interface, and image processing algorithms. Within the camera as a whole, and indeed within each of these technical individuals, there exist a multitude of technical elements. The technical elements of the lens are: two separate lenses, a focus ring to alter the distance between them, and an aperture iris. Similarly, the technical elements of the sensor would include its silicon substrate, bayer filter, shift register and output amplifier.

Simondon describes the genesis of a technical individual as a process of concretisation:

> the primitive technical object is not a physical natural system but a physical translation of an intellectual system… The concrete technical object, that is, the evolved technical object is quite the opposite in that it approximates the mode of existence of natural objects. It tends to internal coherence and towards the closure of the system of causes and effects which operate in circular fashion within its boundaries. (1980: 46)

Applying Simondon's thesis to the concretisation of the digital camera as a technical ensemble leads us to the realisation that at the point of its invention the image sensor is by far the most primitive technical individual within the ensemble, in spite of being generally understood as the most advanced. By the time the CCD is invented in 1969, the camera is already a highly concretised ensemble, one whose genesis spans several different technologies of image

[3] As explored in the recent theoretical work of Jennifer Gabrys (2011), Jussi Parikka (2015) and creative projects such as Jonathan Kemp, Martin Howse & Ryan Jordan's *Crystal World* (Kemp, 2013).

reproduction and, through the camera obscura, long precedes photography. Even the LCD screen, by virtue of building on the genesis of screen technologies in general and the colour CRT in particular, can be described as considerably more evolved than the image sensor. From this Simondonian perspective we can understand the first digital cameras as *incoherent* technical objects in that "the coherence of a technical ensemble is made up of sub-systems with the same level of relative individualisation" (1980: 70). Furthermore, this highlights the extent to which the concretisation of the digital camera over the past 30 years has been driven by developments in sensor technology and the advancement of image-processing techniques[4]. Insisting on the sensor, screen and processing algorithms as distinct technical individuals, and having an awareness of their separate concretisations, will enable us to distinguish their individual amplifications and reductions of perceptual experience.

There is a notable confluence between the process of concretisation outlined by Simondon and Barad's understanding of "the materialisation of an apparatus" as "an open temporal process" (2007: 203). In the concretisation of the image sensor from patent through scientific instrument to consumer technology and into its future applications in machine vision or bodily appendage, we can see an apparatus not as a pre-existing or fixed entity, but instead in the manner Barad describes apparatuses as "constituted through particular practices that are perpetually open to rearrangements, rearticulations and other reworkings" (2007: 203).

Simondon speaks of technical individuals as having an "associated milieu" (1980: 72) when their actions are both contingent and affective on their environments. He offers the example of the traction engine, which has both a technical environment and a geographic environment: "two worlds that do not belong to the same system and are not necessarily compatible with each other" but, "through the traction engine the two worlds act on one another" (1980: 54-5): they intra-act. Seen in these terms the associated milieux of the sensor and screen can be defined as follows. Both are contingent on a technical environment of micro-temporally precise fluctuations in voltage to maintain normal operation. The sensor is then also affective on this technical environment: its output of data providing an input to the camera's memory and subsequently its screen. The nature of the external environment upon which they are contingent and affective is that which Ihde and Hansen respectively describe as 'world' and 'worldly sensibility'. In the case of the screen this environment can be described as perceptual or psychophysical, due to the calculative nature of its relation to human sight, and this chimes with Simondon's understanding of the user as "becom[ing] the associated milieu of different tools he uses" (1980: 91). In the case of the sensor, however, its external environment is one of light

[4] This stark realisation presents a powerful ecological critique of the camera industry, which, if only for a little foresight and preemptive standardisation, might have sold consumers regular sensor and operating system upgrades rather than wholesale replacements.

which, as demonstrated in the laser and X-ray assays, exceeds the visible: its environment is photonic. We can therefore describe the camera ensemble as a whole as being contingent on a photonic environment and affective on a psychophysical one.

Technical elements, writes Simondon, "have a transductive property that makes them the true carriers of technicality" (1980: 88). For him, transduction is the process by which both technical objects and human beings individuate, and includes "physical, biological, mental or social operation[s]" (Coombes 2013: 6). As such it is central to the genesis of the individual and denotes processes of continual transformation. Both sensor and screen are, also in engineering terms, transducers. The sensor transduces light into voltage, photons into electrons, from a photonic environment to an electronic environment. The screen meanwhile, does the inverse, transducing voltage into light, electrons back into photons, from an electronic to a psychophysical environment. This understanding of the doubly transductive nature of the digital camera is crucial to understanding how this technology mediates between photonic and psychophysical space. In contrast to the singular transduction of photosensitive chemicals in analogue photography, in digital cameras we find two entirely distinct transductions each of which is enacted by equally distinct technical individuals of the camera ensemble. Just as with Adrian MacKenzie's example of the pendulum clock, the camera ensemble mediates between "two divergent realities, one facing towards geographical-terrestrial space, the other facing towards a social milieu of symbols" (2002: 106). It is therefore only within the camera ensemble as a whole that the reciprocity which Simondon observes in the traction engine and MacKenzie in the pendulum clock can be seen. It is the equal and opposite transduction by the screen which reciprocates the information transduced by the sensor back into our perception.

In a footnote to the introduction of *Transductions*, MacKenzie proposes that "we could also approach transduction starting from technical elements known as 'transducers'" and it is exactly that which I propose to do here. He goes on to offer the following definition:

> For the process of transduction to occur, there must be some disparity, discontinuity or mismatch within a domain; two different forms or potentials whose disparity can be modulated. Transduction is a process whereby a disparity or difference is topologically or temporally restructured across some interface. (2002: 25)

My account of the camera's perceptual technics is therefore a *transductive* one; exposing the disparities and discontinuities between our natural photonic environment, the technical environment of the digital camera and the psychophysics of human perception. In doing so I expose how the camera as a whole, and its individual technical components, transduce between these domains. In Barad's theorization of phenomena, these three agencies: the physiological and technical ‘agencies of observation’, and the agency of the object or reality observed are not understood as distinct but entangled, and only definable in the knowledge and moment of their specific conditions of intra-action.

Before embarking on an in-depth analysis of the three major components of the camera: sensor, screen, and processing algorithms, I will outline briefly my understanding of the post-optical and its importance in understanding the functionality of the digital camera.

Post-Optics

For the vast majority of history optical technologies have operated by focusing or reflecting light onto the human retina. Over the course of the last century, however, our definition of optics has been forcibly expanded by the scientific, technological, medical and medial colonisation of areas in the electromagnetic spectrum beyond the visible range. Optics have been rapidly instrumentalised far beyond the temporal and spectral limits of human perception. “Photography”, writes Akira Lippit, “crossed the threshold of the human body with the penetrating light of the X-ray” (2005: 29) and, at the opposite extreme of the visible spectrum, an infra-red wavelength reads data encoded optically on CDs from tracks 1.6 micrometers apart. Information is transmitted in fibre optics as invisible yet blinding light: in 2012 researchers at the University of Southampton transmitted data at a rate of 73.7 TB per second in a hollow core fibre optic cable, at 99.7% of the speed of light. The optical now not only exceeds the visible in terms of wavelength, covering a spectrum from microwaves to x-rays, but also in terms of process: optics beyond the visible are increasingly instrumentalised in storing and transmitting data.

Opticality now encompasses the visible and the invisible. As Trevor Paglen writes: “visual culture has changed form. It has become detached from human eyes and has largely become invisible” (2016). Derrida posits two separate orders of invisibility. The first, the “in-visible”, is merely that which is hidden from sight. The image sensors inside cameras and phones are of this order of visibility. There to be seen, but obscured inside the sealed unit of the camera, for Derrida, “whatever one conceals in this way becomes invisible, but remains within the order of visibility” (2008: 90). The second order of invisibility, which he terms “absolute invisibility”, is “whatever falls outside the register of sight” (2008: 90). Although Derrida only explicitly names those vibrations perceptible to other senses, this must also be seen as including the imperceptible portions of the electromagnetic spectrum. Helmholtz concurs, stating that “the distinction between visible and invisible rays depends only on the length of their waves… we call these middle rays light because they alone illuminate our eyes” (Warren & Warren 1968: 87). It is this second order of invisibility: "the nonvisible as that which is other than visible" (Derrida 2008: 90) with which I am concerned here in my definition of the post-optical.

In digital cameras then, the optical only accounts for a small fraction of its perceptual technics, the majority occurs in the absolutely invisible informatic space of computation. To address the post-optical operation of contemporary technologies we must not only expand our notion of optical, but also look to that which exceeds opticality. Carolyn Kane offers the following definition:

> In contrast to an optical image like a photograph or film, an algorithmic image is a *system* operating through post-optic principles of informatic reduction, predictive scanning and the allegorical presentation of data" (2014: 18).

The post-optical can therefore be understood as synonymous with the informatic. The in-visibility of the sensor within the camera stands as only the beginning of photography's concealment from sight. These informatic processes: the image processing algorithms and compression codecs by which digital images are processed prior to display, belong to Derrida's order of absolute invisibility. Contemporary vision is captured, filtered, structured, and reconfigured by blinding optics and invisible informatics, what Lippit describes as the *a*visual: "the avisual image … determines an experience of seeing, a sense of the visual, without ever offering an image" (Lippit 2005: 32).

The expansion of optics beyond physiological limits addresses what Maurizio Lazzarato describes as "the error of the optical model with regard to the apprehension of vision", which he identifies as extracting "the eye and the retinal image from a continuous and cohesive process that includes the object, the brain, the nerves and the retina itself." (2007: 104). In order to fully address the limitations of a purely retinal model of visual perception and perceptual technics, it will therefore be necessary to take into account the neurological processes of visual cognition and the post-optical algorithms that emulate them. The following three sections comprise close comparative readings of: firstly the image sensor and retina, secondly the LCD screen and visual perception, and finally of video codecs and visual cognition.

A Grammatology of Image Sensors

In his "machine reading" of the magnetic hard drive disk, Matthew Kirschenbaum (2012: 86-96) appropriates Derrida's notion of grammatology, applying it in a media theoretical context. Although Kirschenbaum makes no case for the relevance of Derrida's "science of writing" (1976: 27) to his close reading of the hard drive, there are several apposite reasons for its application to digital technics in general and the digital camera in particular. Bernhard Stiegler, for one, has referred to the digitisation of the image as the beginning of "a vast process of the grammaticalisation of the visible" (2002: 149). Wolfgang Ernst, too, posits the digitisation of signals as a return to the dominance of linear, alphanumeric textuality, explicitly analogising the transition of continuous analogue signals into discrete digital data to language:

> The vocal alphabet as writing system emerged as an attempt to analyse and thereby literally dis-connect continuous oral speech into individual elements – thus creating the linguistic notion of phonemes as such. (2016a: 132)

The encoding of images as a string of discrete pixels does for the image what the alphabet does for language (see also Siegert 2018: 10). According to Derrida, phonemes create "a certain kind of structurally and axiologically determined relationship between speech and writing" (1976: 27), while the digital camera breaks down the continuity of our photonic environment both temporally, into frames, and spatially, into pixels. The camera's technics thereby enforce a similar structurally and axiologically determined relationship between its environment and its images. Pixels, and their representation in binary code, also conform to Derrida's assertion that "the written signifier is always technical and representative. It has no constitutive meaning" (1976: 11). A pixel has no direct correspondence with a "transcendental signified" (1976: 49) such as that between written and spoken language which Derrida so meticulously deconstructs. The individual pixel neither represents an object, nor even (as we shall see) a specific number of photons. Pixels are not therefore a fundamental expression of an external reality, but rather the result of a computational interpretation of that reality through a highly specific and structured system of image-writing. Here we find a relation with Barad, who insists that "zooming in on any practice of image formation – including point and shoot cameras – will make it clear that images don't simply capture what is already there" (2007: 411). For Barad then, "the referent is not an observation-independent object" (2007: 198) but is produced by the presence and technical specificity of the apparatus by which it is observed. Furthermore, the camera image occurs only in the moment that this writing system and human visual perception intra-act. It does not exist as an image prior to the shutter being released nor in the microtemporal process of capture. The image itself must therefore be understood as *originating* not in the photonic environment but in the technics of the camera. The digital camera is a writer of images, or as

Flusser so often insists, a pro*gramm*er of images: an apparatus for the grammar of the visible. The camera is an image computer - perhaps even *cam*puter - it computes images.

Using the concept of grammatology can also enrich our understanding of the camera as a technical ensemble. Hayles, in her discussion of the coevolution of humans and tools, connects "the fabrication of compound tools" to "the expansion and development of language" in that compound tools "involve specific sequences for their construction, a type of reasoning … which is also instrumental in language use" (2012: 90-1). In this way, we can see the concretisation of the digital camera ensemble as a grammatological process in itself.

In considering the transductions performed by the components of the camera grammatologically I will address the following questions posed by Derrida:

> On what conditions is grammatology possible?... On the condition of knowing what writing is and how the plurivocity of this concept is formed. Where does writing begin? When does writing begin? Where and when does the trace… narrow itself down into "writing" in the colloquial sense? Where and when does one pass from one writing to another… from the *trace* to the *graphie*, from one graphic system to another and, in the field of graphic code, from one graphic discourse to another? (1976: 74)

By applying these conditions for grammatology to the camera, we will be able to better understand where and when in the process of digital photography the image is written. And by understanding the passage between these writing systems as distinct transductions, we will be able to distinguish the discrete mechanisms by which light from our photonic environment is programmed into images: the technical conditions under which contemporary visual subjectivity is constructed.

I will now examine with more rigour the comparison made at the beginning of this chapter between the retina and image sensor (figs 12 & 13). The basis of this comparison is simple: the sensor is hardwired into the camera and consists of a photosensitive surface divided into individual cells - photosites. Beyond this fairly superficial correlation there are some equally obvious disparities. Human vision is binocular, whereas machine vision is almost universally monocular. In place of rods and cones a sensor has only one type of sensitive cell, so chrominance and luminance can be measured at the same site. Colour sensors, however, are masked by an integral Bayer filter, making individual photosites sensitive to one of the RGB primaries, as are retinal cones. Crucially, whereas in Helmholtz's description of the retina "each rod is connected with one of the minutest of nerve fibres, each cone with one somewhat thicker" (Warren & Warren 1968: 68), the output from the sensor flows sequentially through a single

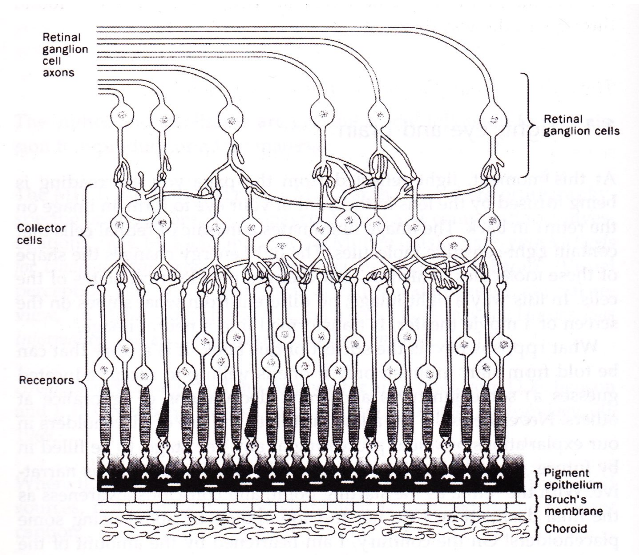


Fig. 12 Diagram showing section through the retina

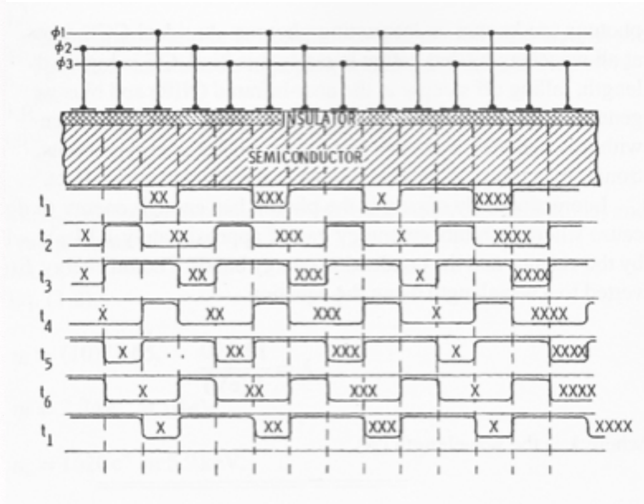


Fig. 13 Diagram showing operation of a CCD sensor

path. Whereas in biological sight the multiplicity of retinal cells operate individually in parallel, digital image capture relies on linear sequential processing and it is the division of the sensor into a grid which enables the charge from the individual photosites to be registered as a linear sequence of code. In a grammatology of the sensor then, the writing of the image begins *before* exposure, in fact before the camera is ever switched on, with the gridding of the photosensitive surface during manufacture. As Cubitt writes, "Thus the grain of a digital image is already arranged in the form of a grid" (2014: 105).

The operations of an image sensor can be divided into optical and post-optical stages. The transduction of photons to electrons in the photosites, variously referred to in the technical literature as *acquisition* or *integration*, is an optical process. Thereafter, the transfer and enumeration of the charge generated, and its encoding as binary information are post-optical. There are two predominant types of commercial sensor used today: CCD and CMOS. Their optical operation is identical. Incident photons passing through the lens are absorbed in the silicon, releasing electrons in the photosites. This entirely analogue process produces a charge in the substrate and is essentially the same as the operation of photo-voltaic or solar cells. This charge, using Derrida's terminology, may be described as the *trace* of light within the chip and it is in the transition from trace to graphie, the post-optical stage of their operation, that CCD and CMOS sensors differ. In CCDs the charge accumulated at each individual pixel during exposure is transferred sequentially up each column of the array into the shift register (fig. 14). The shift register - a horizontal row of photosites outside of the exposure area of the chip - provides temporary storage for a single row of pixels, which are then readout horizontally through an analogue to digital converter. Whereas in a CMOS sensor, each photosite has an "adjacent charge-to-voltage converter, buffer and other preprocessing circuits … and their voltages are collected and transferred … using the row-column addressing mechanism" (Sinha

2012: 103). In CCDs then the trace persists almost to the edge of the sensor, whereas in CMOS sensors it is converted to the *graphie* directly at the photosite.

The rectilinear gridding of the sensor's surface seems at first to be peculiar to media, an abstract means of rationalising visual space. However, Helmholtz speaks of the rods and cones of the retina as "closely packed together, so as to form a regular mosaic layer behind it" (Warren & Warren 1968: 68). This turn of phrase coincidentally recalls the use of a de-mosaicing algorithm to reconstruct a full colour image from the individual RGB pixel data outputted by the sensor. This correlation becomes more complex, however, when one considers the relative acuities of retina and sensor.

Due to the uneven distribution of rods and cones, acuity in the retina varies dramatically between the centre and periphery. In the fovea (the central portion of the retina) Hemholtz speaks of human vision being "so accurate that it can distinguish the distance between two points… equal to the sixtieth part of the diameter of the finger nail" (Warren & Warren 1968: 71) but this acuity drops off rapidly outside the central pit. By contrast, in the sensor, resolution is necessarily uniform across the whole surface. As noted by Helmholtz:

> we are accustomed to expect in these instruments complete precision of the image over its entire extent, while it is only necessary for the image on the retina to be exact over a very small surface (Warren & Warren 1968: 71).

This uniform resolution, familiar throughout the history of optical technics, might be conceived of, in Ihde's terminology, as an amplification of the mono-dimension of visual acuity, an extension of the perceptual abilities of the fovea across the whole picture plane.

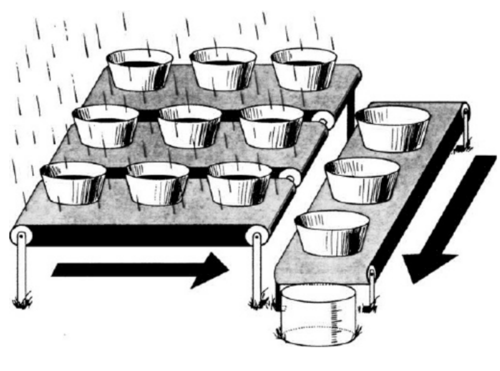


Fig. 14 Diagram of charge transfer in a CCD sensor

In terms of spectral sensitivity both image sensor technologies far outstrip human perceptual faculties, with CCD sensors being far *more* sensitive to the infra-red spectrum[5] than to blue or violet (fig. 15). For this reason, consumer grade cameras are fitted with infra-red filters to restrict their operation to the visible spectrum. This underlines the extent to which image sensors are in no way a human-addressed media, but rather, as Hansen describes all twenty-first century media, "correlate to no already existent human faculty or capacity" (Hansen 2015: 4). The correlation to human faculties is instead achieved by separate technical elements, namely the infra-red and bayer filters, which first confine photonic capture to the visible spectrum and then divide image space beneath a mosaic which replicates the trichromatic sensitivity of the retina (fig. 16).

According to Simondon "information literally in-forms a machine, or imparts a form to it" (MacKenzie 2002: 26). This can be seen in the genesis of the image sensor, from its patent as CCD to its concretisation as sensor. Charge-coupling itself – the mechanism by which the chip transfers electrons between pixels - has no specific form, beyond that of a grid whose operation is consistent but whose function is indeterminate. It is the application of photonic information to its technicity which imparts its form. For Simondon, "the more advanced the technicality of an element becomes, the more the margin of indetermination of this force diminishes" (Simondon 1980: 88). Hence the CCD, as patented, contains a large margin of indetermination. If "it is such a margin that allows for the machine's sensitivity to outside information" (1980: 4) then the margin retained by the CCD sensor is significantly narrowed, located in the potential well of its pixels and restricted to light from the visible spectrum to be measured for luminance and chrominance according to an RGB system.

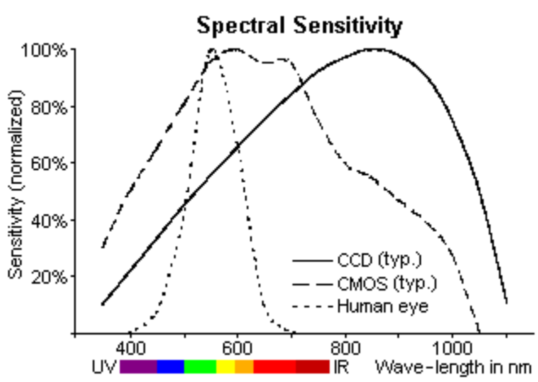


Fig. 15 Graph of relative spectral sensitivites

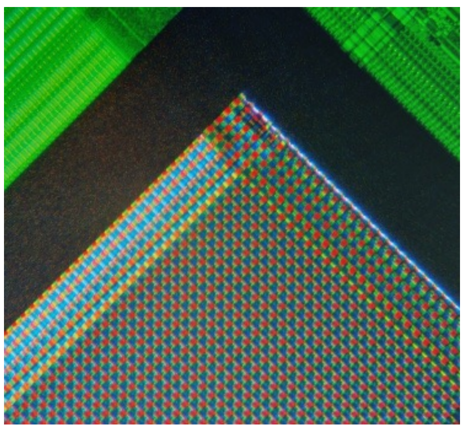


Fig. 16 Micrograph of an image sensor

[5] See Pierotti & Ronetti 2018 for an account of the historical importance of the infra-red spectrum to surveillance, military and medicinal applications.

Seen in this context, we can conceive of the current transition from CCD to CMOS sensors as a stage in the sensor's ongoing concretisation, albeit one in which economic motives play a defining role, and which should therefore be understood as ideological. Simondon remains notably silent on the motivations which lie behind processes of concretisation and the industries which drive them. But Franco Berardi, in his discussion of the relationships between artist, economist and engineer, speaks of the past century as one in which engineering "has finally been submitted to Economics, through a reduction of the technical possibilities to the single-minded economic determination" (2015: 198). The shifting context of image sensors: from research science through their rapid uptake and development by space telescopy and the military, to the market-driven economy of consumer electronics, provides a case in point of this reduction to single-minded economic determination. Once the image sensor becomes part of a consumer product it is concretised with economic logic, its specifications driven by what Berardi dismisses as "dogmatic notions such as growth" (2015: 198). In consumer electronics, the sensor's concretisation has been driven by an industry intent on maximisation solely according to quantitative metrics (such as mega-pixel count) rather then through the more nuanced debate to be found in scientific circles (e.g. Smith & Tatarewicz 1985).

As Simondon writes: "the real stages of improvement of the technical object are achieved by mutations, but by mutations that have meaningful direction" (1980: 62). Understanding the operational differences between CCD and CMOS evidences what is 'meaningful' in this concretisation. The fact that "a CMOS sensor offers more flexibility for outputting the image data" and is considered "well suited for high volume consumer electronics where storage space and low power are preferred at the expense of reduced image quality" (Sinha 2012: 103-4, 117) clearly demonstrates the consumer camera industry's priorities. The immediate transition from trace to graphie in CMOS sensors not only shrinks indetermination temporally but contains it spatially at the local level of individual pixel rather than within the global charge transfer process of CCD chips. Light is written directly to code on impact: abstraction is immediate. In the drive for instantaneous image transmission even this micro-temporal difference in readout rates becomes critical. In this economic logic, image quality is a secondary concern, and one that, as we will see, can also be post-optically synthesized by algorithms.

A similar dynamic, in which speed and convenience for transmission are prioritised over visual veracity persists throughout the writing of the image. As Cubitt points out, the enumeration of light into electrons occurs through a series of averaging functions. Firstly, an averaging of the "photon flux over the area of the pixel for the duration of the exposure" (2014: 106) enables a whole number to be attributed in place of the millions of individual photons that strike each pixel. Colour too is subjected to a similar process "by averaging the different wavelengths"

(2014: 105) that reach each pixel during exposure, meaning that micro-variations in chrominance tend to be smoothed, a tendency then repeated by noise reduction processing. These practices are amplified further in some cameras by the practice of *pixel binning*, a process which averages the charge collected across an area of neighbouring pixels. "The typical binning array sizes of 2x2, 3x3 and 4x4 give improved readout times by factors of 4, 9 and 16 respectively, but with corresponding reductions in the number of output pixels" (Sinha 2012: 133). These averaging practices all tend towards the homogenisation of micro-variations in spatial detail and therefore contradict the drive towards ever higher resolutions. Here, resolution is downgraded even before the charge is readout, sacrificed in the drive to eliminate delay. Minimising the delay in the image's appearance on screen always takes precedence over its spatial resolution. Instantaneity is privileged over acuity.

Such inextricable correlations between spatial and temporal metrics of sensor operation become more critical still in video capture, due to the added consideration of frame rate. High speed motion capture applications, where the entire array must be captured 50 or 60 times in a second, often operate at or near the limit-speed of the chip, meaning that a doubling of frame rate necessitates a halving of resolution. Although from a user's perspective the duration of exposure is clearly time-critical, the post-optical processes of enumeration and encoding are equally time-critical, but within an entirely different temporal range. For Ernst,

> Time-critical does not mean simply that media operations are time-based… rather this concept means that medial operations under the condition of digital signal processing must be processed in strictly defined windows in order for… a message to materialise at all. (2016: 10).

In the case of the readout rate of image sensors this window is defined in relation to the operation of other technical elements of the camera ensemble, principally the shutter speed. In digital cameras the mechanical shutter operates in conjunction with an electronic shutter that controls the integration time of each row. Following acquisition all pixels must be readout before another exposure can occur. This process is known as *clocking*, "the frequency of this clock controls the exposure time of the photo elements" (Sinha 2012: 121). For a video to appear this clock must readout all pixels within the perceptually defined moment of a single frame. The downscaling of resolution between still and video modes of a camera is a direct result of this negotiation between the psychophysical limits of human visual perception and the micro-temporal limits of these on-chip post-optical processes. The materialisation of what we perceive to be a moving image is contingent upon an imperceptible electronic micro-temporality operating within the bounds of a psychophysical temporality.

The dual functionality of the CCD's silicon substrate as both a photosensitive surface and temporary memory serves to maintain the fluidity of the video signal. In the shift register we can observe what Ernst characterises as an *extension of the present*: "registers serve here… as momentary buffering and thus constitute part of the present window rather than part of memory" (Ernst 2016: 31-2). This perpetual buffering of the present enables another frame to be exposed during the readout of the previous frame. However, as Cubitt points out, it also introduces latency: a time delay between "the disappearance and reappearance of the technical image" (2014: 102), into digital photography (see also Fontcuberta 2014: 37). This delay is mitigated against in CMOS sensors by further instrumentalising the silicon. While this could be understood as fulfilling one of Simondon's characteristics of concretisation: that "each structural element fill[s] several functions instead of one" (1980: 27), in the consumer camera industry such concretisation doesn't escape the pernicious logic of the market.

These micro-temporal reductions of latency in digital photographic technics are consistent with the broader cultural tendency identified by Fontcuberta as "the drive to shorten the interval between taking the picture and being able to see it" (2014: 23). For MacKenzie, this hastening of appearance has become the defining trope of the informatic visual spectacle:

> The value of information equates to the time of its circulation … To have something faster, sooner, now rather than later is what defines the value of information as a commodity. (2002: 159-60)

This desire for instantaneity is matched by one for ever higher resolutions. In his discussion of computer games MacKenzie alludes to "a rough equation between more polygons per second and the game machine as a commodity form" (2002: 159). It is this equation, MacKenzie contends, which governs a game's profitability, and the same can be said of the mega-pixel escalation witnessed in the camera industry. Yet, as we have seen, in beginning to unravel the

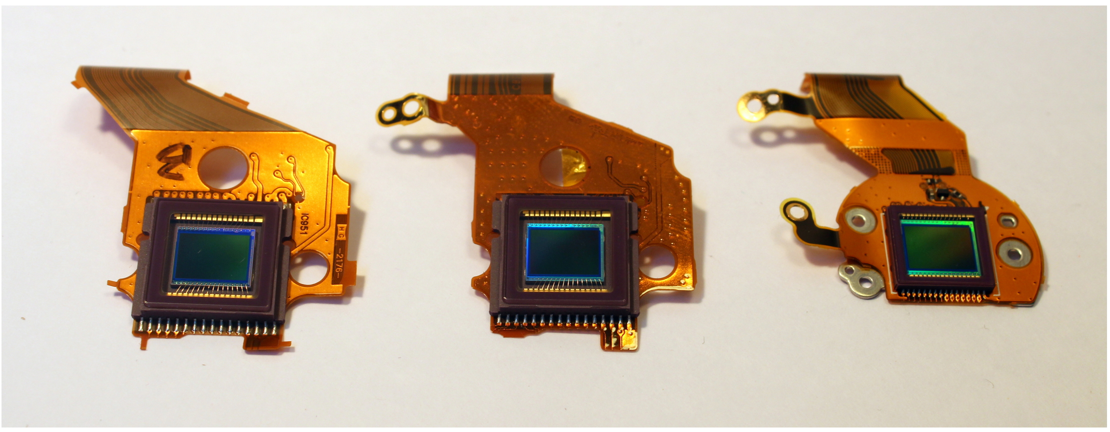


Fig. 17 Concretisation of a CCD: image sensors from Fuji A600, A800 & A900 compact cameras

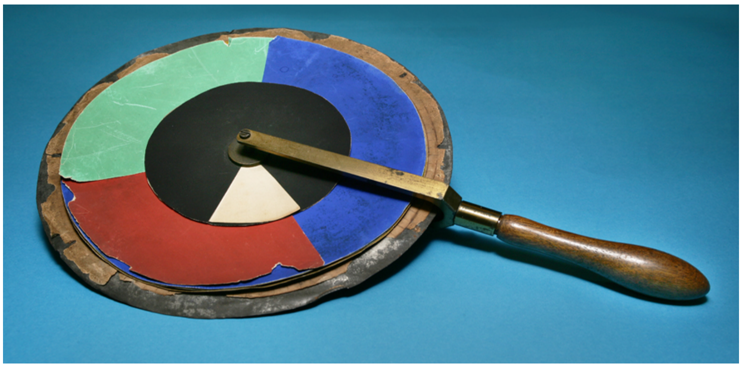
post-optical processes of digital image technics, latency and resolution are necessarily proportional to one another. As resolution increases either the latency or the clocking frequency must also rise to maintain the sensor's temporal relationships with the other technical elements of the camera. If we add to this the current tendency towards miniaturisation then we can see the further concretisation of image sensors as being caught in an ever tightening spiral of seeking to deliver higher resolution with less latency on a smaller chip (fig. 17).

In spite of their superficial resemblance to the retina, the structure and operation of image sensors presents a radical departure from the notion of visual media as human-addressing. In the linear rationality with which they deconstruct visual space, their broad sensitivity to wavelengths far beyond the visible spectrum, and the imperceptible micro-temporality of their clocks, image sensors address themselves to photonic and informatic regimes which are simply insensible to humans. The transduction they effect can therefore be understood as mediating between the diverse realities of our photonic environment and the algorithmic environment of digital computation; in short, a transduction which is thoroughly imperceptible to human consciousness. Sealed within the camera's interior, the sensor inhabits Derrida's first order of in-visibility, while its spectral sensitivity offers unprecedented access to his second order of absolute invisibility: the electromagnetic spectrum beyond human sight. The image sensor is a technology of sight to which anthropocentric notions of visibility are purely incidental.

Phenomenologically speaking, image sensors exhibit a profoundly "unexperienced opacity" (Ihde, 1979: 37) on three levels. They are concealed from us, their mode of operation is post-optical, and the extra-visual light they transduce is filtered out by infra-red and bayer filters: the sensor's only human-addressed elements. These tendencies: for exclusion, for spectral reduction and for chromatic prescription, persist in the second of the camera's transducers, to which we now turn our attention: the liquid crystal display.

A Grammatology of the LCD Screen

Unlike the sensor, the liquid crystal display (LCD) screen, one of the key technical individuals in the camera ensemble, finds its genesis in a long history of screen technologies. The process of additive colour synthesis central to its operation is found in cathode ray tubes (CRT) and its history dates back to Thomas Young's hypothesis of sight as consisting of "three principle colours", which presciently argued that "each sensitive filament of the [optical] nerve may consist of three portions, one for each principal colour" (1802: 21). Young's theory was subsequently proven by Hermann von Helmholtz and elaborated upon by the experiments of



Figs 18 & 19 James Clerk Maxwell's colour wheel & a colour wheel from a DLP projector.

James Clerk Maxwell. Maxwell's colour wheels were the first methodological test for the theory of trichromatic vision and "an early example, if not the first, of a psychological question receiving a direct empirical test" (Sherman 1981: 170). Maxwell's conclusion - "that the judgment thus formed is determined not by the real identity of the colours, but by a cause residing in the eye of the observer" (Sherman 1981: 169) - was crucial in establishing an understanding of human vision as a manipulable system of perceptual limitations. Maxwell posits a direct opposition between a supposedly empirical reality and a fallible perception, one which persists throughout our contemporary media environment. Ihde refers to this notion of the world as constituted primarily by technical means as *instrumental realism* (1979: 46). Maxwell's colour wheel persists today, not only in the psychophysical principles of colour vision and the algorithmic colour spaces which media standards have derived from them, but also as a techno-chromatic mechanism in contemporary DLP (digital light processing) projectors (figs. 18 & 19). The RGB colour system of the LCD screen is managed within the pixelate form of the raster grid, the same system as that used in the development of colour television, although as Cubitt points out (2011: 26) CRT monitors are considerably less rigid in their application of this grid. As the technical literature makes clear, the rigidity of the LCD is a product of the

> matrix-addressing scheme common to practically all flat-panel display types … Unlike the CRT, which readily accepts a continuous video signal, the flat-panel types require that the video information be provided in discrete samples (Myers 2002: 61-2).

This matrix-addressing system is the exact inverse of that found in CMOS sensors and ensures the location of each pixel within the grid. Although addressing is here meant in the topographical sense, the screen is also contingent upon - addressed *to* - this matrix: to a Cartesian, informatic space. Regarded not as separate technologies but as stages in the concretisation of the screen, the transition from CRT to LCD brings economic and ecological benefits such as lower power consumption and fewer toxic components[6]. There is, however, a functional cost in the degree to which the LCD rationalises and regiments image space, whereas a CRT is able "to adapt quickly and easily to a wide range of image formats… [and] does not have an inherent fixed format of its own" (Myers 2002: 60). This adaptability – what Simondon refers to as a *margin of indetermination* – is considerably narrower in the LCD. No longer is this a transducer capable of visualising indeterminate signals[7], but instead one which redistributes determinate data values within a prescribed form(at). If, as Simondon has it, "the machine with superior technicality is an open machine" (1980: 29) then this increased determinacy can also be conceived of as technically regressive. Viewed as stages within the concretisation of screen technologies, the transition from CRT to LCD, similar to that between CCD and CMOS, represents a reduction of indeterminacy, a closure of the machine's transductive potential to all but a highly regulated and determinate signal.

A comparison of LCD screens with DLP projection systems futher demonstrates the correlation between time and space in media architectures. In both instances the colours perceived are simply not present from a medial perspective. In DLP projection, colour is synthesised temporally by the sequential projection of separate mono-chromatic images, whereas in LCD systems, colour is synthesised spatially, so what is perceived as pure white is achieved by a repetition of neighbouring RGB stripes distributed across the field of vision. Thus, a screen which is perceived to be 100% blue is actually 67% black. From a media historical perspective this can be understood as a spatial redistribution of the black spaces between frames in analogue film projection. Both cinematic and televisual media operate by segmenting the image into sub-perceptual fragments: the former temporally, the latter spatially as well.

The LCD screen operates through a technical mimicry of the trichromatic sensitivities of the retinal cones. For Derrida, "what it [writing] distributes in space is alien to the order of the voice" (1976: 9), but the opposite is true of the LCD. Far from being alien to the order of the eye, the LCD has an entirely deterministic relationship with the physiology of vision. The imperceptibility of its RGB raster grid is prefigured in the standard psychophysical test for visual acuity, in which black and white stripes of variable width merge into a shade of grey at some scale or distance from the subject. Helmholtz's description of foveal acuity states that:

> in this small part of the field our power of vision is so accurate that it can distinguish the distance between two points ... This distance corresponds to the width of one of the cones of the retina. (Warren & Warren 1968: 71)

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[6] See Cubitt (2011) for a more detailed assessment of the various impacts of this transition from CRT to LCD screens.

[7] As seen for example in the Cathodic works of video artist Aldo Tambellini.

This direct relationship between the physical scale of the retinal cones and the acuity of human sight leads to the probability that the pixels in contemporary LCD screens correlate directly with a micro-dimension of our own anatomy. Visual acuity is therefore not only analogous to resolution but also proportional to it: the LCD's mimicry of the retina's chromatic structure includes a determination of size. This consideration of scale adds weight to the chromatic argument proposed by Kane, in which she conceives of watching television as "a cybernetic loop where the signal is integrated with subjective perception, eradicating any clear distinction between subject and object" (2014: 97).

Already then we can see one major difference between screen and sensor. While the sensor is addressed to its photonic and informatic environments, the screen is explicitly human-addressed. While it is obvious that screens are designed to be seen by eyes, this enables a comparative analysis of the camera's two optical transductions that exposes the extent to which the opposition between perception and empirical reality established by Maxwell is embedded in the technicity of visual media.

Although an LCD screen is a two dimensional "Cartesian coordinate space" (Cubitt 2011: 26), it is designed to function with respect to a third dimension: distance from the viewer. In the context of the camera this distance is consistently close, what engineers refer to as a "near-eye application" (Myers 2002: 77). In phenomenological terms however, Ihde identifies this proximity as a universal quality of visual media: "appearance mediated by an optical instrument is one marked by a fixed near-distance … this phenomenal distance is the same for both telescope and microscope" (Ihde 1979: 75). But although the handheld near-field touch-screen of contemporary cameras appears to offer a similar experience, its conflation of sight and tactility on the same surface makes for a more complex relation.

This is perhaps best examined in comparison with another medial combination of sight and touch: the television and remote control. In this situation phenomenological experience is of two separate instruments, the former extends vision beyond the room, the latter extends manual control beyond our reach, we experience both independently as embodied instruments. When using the remote control the screen is dominated by a menu system: the technics of the media system obscures the transparency of the image, but, once the menu disappears, we settle back into an embodied tele-visual relation. In the case of the touch-screen these two independent technical relations are conflated, not only within the same ensemble, but the same *technical individual* of this ensemble. While this provides an important example of the dual functionality which Simondon stresses as crucial to concretisation (1980: 27), it also presents a barrier to embodiment. Our experience of the screen constantly oscillates between the visual and the instrumentally tactile, between display and graphic user interface, between surface and illusionistic depth, increasingly overlaid on each other. Given that Hansen's account of embodiment stresses "the tactile basis of vision" (2006: 123), we might consider this convergence of two senses to aid in our embodiment of the camera. However, the touchscreen could hardly de described as offering "a tactile experience of the body's interpenetration with the environment" (2006: 130). Instead, our tactile experience is only of the smoothness of the camera screen as an instrumental control surface. As Alessandro Ludovico writes: "this anaesthetisation of touch to only gesture-based behaviours channels them to a purely functional role" (2016: 106). As a result, during use, our experience is persistently of the apparatus foremost and of the image only as a product of the camera. This helps to explain the reliance of digital photography on the process of image review, as it is only then that we experience the image without negotiating the technics of the camera. But the integration of this process of review within the act of photography – and of a screen within the ensemble of the camera – shifts the emphasis of photography from an act of composition to one of consumption.

I have concentrated so far on the spatial aspects of the LCD's operation. However, its temporal operation, while far more derivative of previous moving image technologies, also requires discussion. Just as with the image sensor, the operation of an LCD is governed by a frequency. As Cubitt writes, "it is attached to a clock function in which the whole screen is scanned in numerical order and refreshed at regular intervals" (2011: 26). Looked at more closely, we find two separate clocking functions: the *update rate* which governs the speed with which images are transferred to the frame buffer, and the *refresh rate* which governs the speed of image reproduction (Myers 2002: 9). The frame buffer, highlighted by Jacob Gaboury (2018) as the technical element which enabled computational media to become screen media, can therefore be understood in the same way as the shift register of the CCD: a further extension of the present. When working in combination, as with the notionally 'live' feed of a video signal from sensor to screen, the shift register and frame buffer serve to suspend the passage of time within the camera. Lazzarato describes the function of video and information technologies as a "cut into the streaming of flows that allows for the specifically machinic organisation of the relation between signifying and asignifying flows" (Lazzarato 2007: 93). It is the pairing of these two technical elements the digital camera, the shift register and frame buffer that enables this cut ot be performed, and it is in this cut that the acquisition of the ephemeral by the logic of the machine is enabled. The camera regulates the flow of images according to its temporal signature, encoding reality to the rhythm of its computational clock. It is in this micro-temporal interval that the camera harnesses its photonic environment as potential future capital, producing a representation as a commodifiable file, an idea I develop further in Chapter 4.

Possibly the most reductive aspect of the LCD's perceptual technics is neither spatial nor temporal, but chromatic. The colour spaces established by broadcast standards are a technical

element that persists through generations of screen hardware. These colour spaces build on a model established, again, by nineteenth century psychophysics. Young's trichromatic theory led him to posit colour as a triangular space (fig. 20). This space was subsequently mapped by Maxwell's experiments in which, "for the first time, colours had been located outside the triangle, thereby giving colours not specifically composed of primaries a physical interpretation" (Sherman 1981: 168). Through the inclusion of brightness, chromatic space began to be defined as three-dimensional, an understanding now codified in the CIE system (fig. 21).
The colour spaces of broadcast standards consist only of portions of the complete perceptual colour space described by the CIE system, often surprisingly small portions. By Kane's account, for example, "colour television actively reduced the colour gamut to the most minimally acceptable range" (Kane 2014: 65). As with the output resolution of sensors, the tendency when defining chromatic spaces has been to prioritise bandwidth economics over perceptual experience. The algorithmic colour spaces of media take explicit advantage of the law of diminishing returns established by Gustav Fechner's theory of the 'just-noticeable difference', which states that "each time the intensity of a sensation increases, greater and greater quantities of the stimulus will be needed to increase it further" (Sterne & Mulvin 2014: 126). The colour space of HDTV, the central triangle of fig. 21, extends only to the near edge of the saturated range, beyond which equal spatial increments would have diminishing perceptual returns. The human-address of the LCD screen can therefore be understood as perpetuating the tendency outlined by Sterne and Mulvin in their analysis of the NTSC standard, which "not only incorporated the capacities of its users into its infrastructure but built its infrastructure to take advantage of their *incapacities*" (2014: 130).

There exists therefore a fundamental disparity between this chromatically *reductive* tendency of

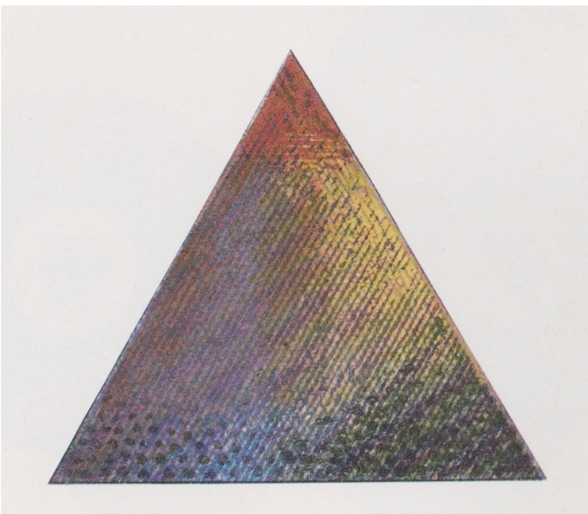

Fig. 20 Thomas Young's Colour Triangle

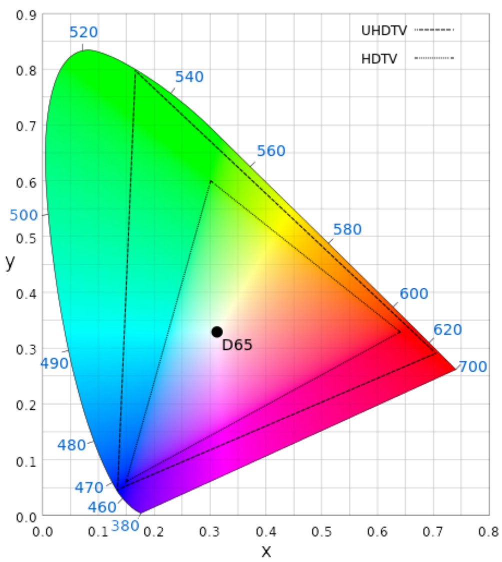

Fig. 21 The CIE colour space with two broadcast standards shown within it.

screen technologies and colour-space-standards and the super and sub-chromatic sensitivity of image sensors. The image sensor has a spectral sensitivity far beyond that of any previous optical instrument, prescribing a potentially massive expansion of technological colour space while the LCD screen and the colour space which it encodes serve to limit perceptual experience far beneath its natural threshold. Technically speaking it is considered:

> physically impossible to produce a practical display, based on a finite set of primaries, which can duplicate any colour within the range of human vision. The only way to do this would be to locate at least one point outside the limits of the diagram, and the outside area represents physically unrealisable supersaturated colours (Myers 2002: 45).

But might not the sensor, by operating exactly within these 'supersaturated' realms of infra-red and ultra-violet, offer a means of access to such 'unrealisable' colours? It is exactly this paradox between, on the one hand, the ability to access and operate in imperceptible spectral and temporal realms, and on the other, the tendency to limit, filter, and reduce spectral and temporal experience for our perception that typifies the operation of contemporary digital media. The LCD can thus be characterised as a reductive transducer, one which, by requiring a specifically formatted signal, delivered in discrete packets of data whose overall resolution can be scaled to the dimensions of its matrix, has a considerably smaller margin of indeterminacy than previous screen technologies. The tendency it perpetuates, of restricting colour space well beneath perceptual thresholds, maintains an attitude pervasive in subjective testing: that media need only offer a satisfactory perceptual experience.

Derrida speaks of the word as a screen: "it is behind the screen of the word that the truly fundamental characteristics of human language often appear" (1976: 32), reminding us of the original meaning of a screen as a partition, curtain or veil. The etymology of the screen, as Erkki Huhtamo has also noted (2004), lies not in objects which tele-visually extend vision beyond its physiological limits, but - on the contrary - in objects which obscure sight. As accessed through the screens of our cameras, phones and computers, our visual experience is more reductive than extensive, more prescriptive than heuristic, "we are thus not blind to the visible, but blinded by the visible, dazzled by writing" (Derrida 1976: 37).

Our bedazzlement by the glowing visibility of screens is not achieved only by the technics of the LCD, but is informatically prefigured in processing that prepares the screen image for its display. In all consumer cameras, the perceptual address of the screen is preceded by algorithmic manipulations of the data captured by the sensor. These absolutely invisible, post-optical computations read and re-write the image numerically, optimising it for perceptual fascination by foreshadowing the neurological processes of early vision.

Video Codecs, Visual Cortex

The technics of the digital camera runs far deeper than its two transducers, and the technics of human vision hardly ends at the retina. To characterise the transition of data between the readout of the sensor and the buffer of the screen as an extension of the present, a pause in the continuum, can give the misleading impression of passivity: that nothing happens in this micro-temporal pause between capture and appearance. Whereas, as Hayles describes in the more time-critical context of high frequency stock trading: "a temporal gap between human and technical cognition creates a realm of autonomy for technical agency" and, within the camera too, this space allows "algorithms [to] draw inferences … and make decisions in milliseconds" (2017: 143). In these scant milliseconds, numerous image processing functions are performed, and the pixel data is algorithmically de-mosaiced and extensively reconfigured, hence, as Fontcuberta writes, "the digital image is always retouched" (2014: 10), even before being seen. Far from objectively capturing some external truth, it becomes impossible to locate with any certainty the qualities of a digital image as originating in either the photonic environment or the circuitry of the camera, but only from the entanglement of the two. As Derrida says of the written word, "in this play of representation, the point of origin becomes ungraspable" (1976: 36).

The typical processing chain of a compact digital camera runs as follows: noise reduction, colour/tone correction, demosaicing, white balance, edge enhancement, compression. Although such processing might at first seem peculiar to digital imaging, there are historic precedents for these processes in scientific imaging practices. Michael Lynch outlines four such "transformative practices" (1990: 160) commonly used in re-drawing scientific photographs as illustrations. These include "uniforming" and "upgrading" which can respectively be seen as direct precedents to noise reduction and edge enhancement. Uniforming consists of using "colour fields, textured spots or cross-hatches, and uniform shading [to] transform variegated fields in the photographs into relatively uniform fields in the diagrams" (1990: 161), a process now automated and invisible in noise reduction algorithms. While in upgrading, "borders are made clear and distinct … and divisions between distinct surfaces are made more definite" (1990: 161), a description that serves also for edge enhancement. We can therefore understand the camera's pre-processing algorithms as deriving from scientific, diagrammatic and *drawn* representative practices, from practices whose aim is to simplify and instrumentalise the image as evidence of a scientific hypothesis.

The operation of these algorithms is achieved through avisual data analysis using processes such as 'fast fourier transform' and 'discrete cosine transform' which translate any given signal into its amplitudes across a frequency spectrum. To recall Derrida's conditions for a grammatology, this is the second time that the image data passes from one graphic system into another, preceded by the digitisation of the signal as it leaves the chip. It is in these processes that digital photography acquires its post-opticality. Although avisual, such techniques must still be understood as perceptual. Not only do these algorithms "exploit the characteristics of the human visual system [and] discard perceptually insignificant data" (Lukac 2012: 124), but their mathematical analysis of relative values of luminance and chrominance across the image plane does "in a certain sense perceive the image" (MacKenzie 2010: 16).

From an engineering perspective, these processing stages are explicitly "constructed to simulate the most important functions of the human visual system" (Lukac 2012: 124). Algorithmic image processing is then, from its inception, designed to externalise neurological functions. For MacKenzie, these programmed imitations of visual cognition in image algorithms, mean that sight becomes conceived as "a sub-representative process that detects differences in brightness, illumination and shadow rather than seeing things" (2010: 14), which is to say as a media-technical system. Hayles names the specific cognitive functions they imitate as "nonconscious cognition", which she describes as "neuronal processing inaccessible to the modes of awareness but nevertheless performing functions essential to consciousness" and in which she includes "synthesizing sensory inputs" (2017: 10). Separating consciousness from cognition in this way allows Hayles to define technical processes such as those realised by image processing algorithms as *technical cognition*: "like human nonconscious cognition, technical cognition processes information faster than consciousness, discerns patterns and draws inferences" (2017: 11). The camera is then one of the numerous "automated technical systems" in which, according to Hayles, "nonconscious cognitions are increasingly embedded" (2017: 24).

The processing stage of a digital camera can therefore be seen as contributing to a now pervasive computational modeling of human subjectivity, a model in which, according to Pasi Väliaho, "the brain and not the eye becomes the primary locus of mediation and 'capture' by which individual bodies and persons are woven into the political reality of contemporary life" (2014, 12). Before beginning an account of the relationship between image algorithms and visual cognition, it is important to remember the extent to which they are mutually entangled.

Throughout centuries of human culture the fixture of images onto a material substrate, whether by pencil, paint or photochemistry has created a false association between images and objects. As Hans Belting writes, however, images "do not exist by themselves, but they *happen*… they happen via transmission and perception" (2005: 302-3). This transductive understanding of the nature of images, by which they only exist relationally in the moment of perception, has a further layer in the context of screen-based electronic images (whether analogue or digital). For just as images are produced in the intra-action of viewer and screen, the electronic image is only visible by virtue of a similar reciprocity between the technicity of the screen and the underlying data. This is what Fontcuberta refers to as the difference between "the latent image and the manifest image" (2014: 37). In all electronic media then, the transductive perceptual relationship between user and content is replicated inside the apparatus. As Laura Marks expresses it with respect to television: "the photon stream utters and the CRT surface interprets" (2002: 168). The electronic image is revisualised anew every time it appears on screen. Similarly in visual cognition, as Ernst points out, "proto-visual information is distributed in the neurons, and it can be reconfigured back into image impressions through similarity-based associations" (2016: 160).

We can observe, in the most basic operation of digital cameras, a chain of transductions moving from photonic to informatic to psychophysical to neurological space. Conceiving this as a chain of transductions has the advantage of allowing us to perceive the continuity of the 'image' through informatic space (as data). So, in spite of the break in both indexicality and what Stiegler terms the "chain of luminances" (2002: 153) caused by digitisation, there remains a continuity between incident light and perceived image. As Marks puts it "digital images are existentially connected to the processes that they image" (2002: 161). Thus we can understand the informatic processing of image data as not only imitating the processes neuroscientists refer to as 'early vision' but also as directly modulating our mental images. Algorithms which are modeled on cortical processes come to directly affect the images produced in the cortex, or, as Hayles writes: "technical devices cognize and in doing so profoundly influence human complex systems" (2017: 5). The combination of camera and user therefore constitute what Hayles calls a "cognitive assemblage", a term which "emphasizes the flow of information through a system and the choices and decisions that create, modify and interpret the flow" (2017: 116). It is therefore not only that we are culturally conditioned to accept the products of the camera as objective reality, but that our nonconscious cognitive perception is begun in the camera, prior to the appearance of the image. Hence we internalise these modifications of the digital image as visual truths. As Berardi expresses it, "digital technology is based on the insertion of neurolinguistic memes and automatic devices into the sphere of cognition, into the social psyche" (2014: 26). Having established the impact that these algorithms might have within visual cognition, I will now proceed with a comparative analysis of the two.

The separation of luminance and chrominance established by the rods and cones of the retina is just the beginning of a "surprising degree of division of labour, by which a seemingly unitary function is carried out" (Farah 2000: 3). Visual cognition, as currently understood, processes the various technical aspects of our photonic environment independently. Edmund Rolls and Gustavo Deco, for example, observe "partially separated neural pathways within the striate cortex that imply a segregation of the processing channels into three functionally distinct pathways" (2001: 50). These segregations, familiar from the image control functions in visual media (e.g. brightness, contrast and colour) are also actively exploited by noise reduction algorithms. Noise, in contemporary image sensors, consists of "stray fragments of charge, quantum effects in the chip" (Cubitt 2014: 106), manifesting as random variations in an otherwise uniform area of colour. These artifacts, negligible in a well-lit scene, increase dramatically in underexposed or darker areas of an image. Noise reduction operates by smoothing out these deviations, but this smoothing can also cause "perceived loss of sharpness or loss of texture" (Lukac 2012: 145). One common solution to this problem exploits our relative acuity for luminance as compared with chrominance, by aggressively smoothing the noise in the chrominance channels of the image while only gently smoothing the luminance channel (Lukac 2012: 148). Whereas in analogue media noise is usually considered a guarantor of authenticity, in the digital image "these last contingent signals from the physical universe subtending the digital camera are experienced as dirt to be cleaned up" (Cubitt 2014: 108). But furthermore, in the specificities of the cleaning process, human visual perception is conceived as a technical system whose flaws can be exploited to conceal "aggressive" image manipulations behind the appearance of a sharp, visually pleasing image. This dynamic, between a perceptually fallible subject and a manipulative algorithmic technics actively seeking to produce a visually 'pleasing' image, is consistent in the technical literature and pervasive in subjective tests.

In some instances, the apparatus' desire to please has even become personalised to its user, as in one example of smartphone algorithms highlighted by Hito Steyerl.

> The trick is to create the algorithm to clean the picture from the noise, or rather to define the picture from within noise. But how does the camera know this?... It scans all other pictures stored on the phone or on your social media networks ... looks through the pictures you already made, or those that are networked to you and tries to match faces and shapes. In short: it creates the picture based on earlier pictures, on your/its memory… it speculates on your preferences and offers an interpretation of data based on affinities to other data. (No date)

The idea of an imaging algorithm adapting to the preferences and habits of its users shouldn't be surprising in an era when our entire media experience is personalised on the basis of previous behaviour, our searches and advertising optimised for our interests - or rather for the most efficient capitalisation of those interests. And yet it fundamentally contradicts the historical conception of the camera as an objective instrument, rewriting the real in accordance with our preferences: truth is redefined as that which we wish to see. The faith that Barthes held in the photographic image as evidence of 'that has been' is shattered and replaced with something that might have been, but certainly looks good. Surprisingly, Väliaho notes some correspondence between this algorithmic autopoesis and human cognition:

> contemporary neuroscience holds that the brain … is a closed, self-referential and self-activating system geared towards generating intrinsic images instead of faithfully 'representing' the external world (2014: 79).

The conception of visual perception as fallible is particularly evident in compression codecs, which, from an engineer's perspective "produce a more efficient representation of the image, in which the redundant and perceptually insignificant data have been removed" (Lukac 2012: 158-9). Human psychophysical limits are inscribed into these processes as a threshold, enabling the economic imperatives of capital to persist even in the micro-temporal space between capture and display. Once again, these processes foreshadow visual perception: "the goals of early visual processing include… removing redundancy from the visual input by not responding to areas of uniform brightness" (Rolls & Deco 2001: 37). Such terminological resemblances between textbooks on visual cognition and technical literature on visual algorithms are striking, and it is through exactly such continual casual parallels that human neuro-subjectivity becomes modeled as computation[8].

One important example of physiological perceptual economics is found early in visual cognition. "Before the image has even left the eye absolute levels of illumination are replaced by a retinotopic map of *differences*: points in the visual field where a light region abuts a dark one" (Farah 2000: 5). This predisposal for image analysis according to relative rather than absolute values is evident in the structure of the retinal ganglion cells which are described as being on-centre/off-surround (or vice versa). An on-centre/off-surround cell is excited by light in a small area of the field of vision and inhibited by light in the adajcent areas, whereas an off-centre/on-surround cell is excited by light in its surround and inhibited by light in the centre. The product of a membrane of such cells, from which all visual perception stems, is a retinotopic map of differential brightness across the image plane. Zylinska describes this cognitive privileging of contrast as essential to sight: "our visual apparatus introduces edges and cuts into the imagistic flow: it cuts up our environment so that we can see it" (2017: 42). This preferential perception of edges is mimicked in the camera's edge enhancement algorithms: mathematical image sharpening which directly targets human perception, processing the image to appeal to our predilection for outlines. This post-optical synthesis of the contour enhancement of human visual physiology directly contradicts the scientific knowledge derived from traditional optics. As Barad writes:

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[8] In this particular instance it appears to be the explicit aim of the authors, whose book after all is titled *Computational Neuroscience of Vision*. There is not space here to critique the pervasive computational metaphor of human consciousness, but interested readers could follow the many leads in both Robert Epstein's article *The Empty Brain* and Andrew Smart's *Beyond Zeros and Ones*.

> there are no sharp edges *visually* either: it is a well recognised fact of *physical optics* that if one looks closely at an 'edge', what one sees is not a sharp boundary between light and dark but rather a series of light and dark bands – that is, a diffraction pattern (2007: 156, my emphasis).

The edge-enhancement algorithms of digital cameras thus serve to reinforce what visual cognition (mistakenly) tells us about the world and in doing so contributes to our certainty in our subjectivity as distinct from the objects around us. This relationship between the technical cognition of edge-enhancement and the differential preference of human visual cognition is emblematic of the extent to which, even in the mundane example of the digital camera, the two are interpenetrated.

The privileging of difference occurs again in the temporal operation of video compression codecs. Unlike film, where each individual frame exists independently as an image, the frames in a compressed video stream exist only as measurements of difference from the previous frame. "Codecs perform encoding and decoding … mainly in the interest of finding what is different in a signal and what is mere repetition … They only move the differences that matter" (MacKenzie 2010: 5). As Cubitt has pointed out (2011: 31) these compression algorithms are therefore predisposed towards static cameras, talking heads or other subjects in which movement is minimised. Again, according to MacKenzie, the drive to economise is embedded within the technics: "at a very deep level, the architecture of an MPEG2 codec reflects the assumption that all movement costs something in time, computation or bandwidth" (2010: 12). MPEG codecs primarily analyse the pixel-blocks of video in terms of their organisation through time, encoding their temporal arrangement as motion vectors. As a result "the frame is no longer the elementary component of movement, but an object to be cut up" (MacKenzie 2006: 4). For Ernst this reinforces the similarity between digital and bodily vision:

> the processing of moving images in humans … resembles current digital image sequence compression processes insofar as it does not store each complete image but rather only the differences to each previous perception" (2016: 45).

However, these correlations between the differential operations of time and luminance in cognition and compression, obscures a far deeper disparity between the two. In visual perception, the spatial retinotopic organisation of the image persists throughout cognition. Two types of optic fibres project from the retina to the six layers of lateral geniculate nucleus (LGN) before continuing to the primary visual cortex. But, in spite of these segregations, the spatial organisation of the image is retained. "The six retinotopic maps in [the] LGN are in register, so that a single point in the visual field is represented by cells directly above and below each other through the different layers" (Farah 2000:10). And the primary visual cortex is also "spatially organised such that retinal topography is approximately preserved" (Rolls & Deco 2001: 47). Unlike the image data stored on an SD card, the mental image can therefore be said to exist *as an image* throughout the process of visual cognition. It is important to emphasise that this in no way means that the brain is capable of 'storing' images. So, whereas the digital image remains archived in code once it has vanished from the screen, the perceived image occurs only in the moment that it is seen. If throughout the camera's transductions from photonic to informatic space the image never exists and only appears on the psychophysical surface of the screen then the inverse is true of the transduction of the image into human cognition, where it can be understood as persisting even within the confines of the brain. Where human cognition preserves the image throughout the cortex, the camera's technical cognition instantaneously dissolves it into a numerical array.

Current neuroscience posits that these anatomical segregations in layers of the visual cortex represent segregations between three main image processing pathways, one of which is responsible for form recognition (Rolls & Deco 2001: 50). Here the disparity with machine vision could not be greater. By measuring relative contrast across the image, cameras are able to perceive edges, widely accepted as the first stage in form recognition. Using this data, imaging algorithms are able to assess and enhance sharpness, and the repetition of this process at various focal lengths is the basis of the auto-focus function in digital cameras. But, in spite of this ability to perceive edges, without access to a vast database of meta-tagged images, camera algorithms are unable to perceive form. According to Henri Bergson's understanding of perception, "the objects which surround my body reflect its possible action on them" (1988: 21), a position supported by neurological research demonstrating that "perceiving a cup handle triggers simulations of both grasping and functional actions" (Hayles 2017: 48). Conversely, for cameras, objects exist only as modulations in the flow of photons. Form recognition, now a standard capability of machine vision systems, can be learnt only with reference to a training set tagged by humans. By this process: "vision is reduced to one or a set of terms which, even if they are detailed, are not able to describe the complexity of perceptual experience" (Treccani 2018). Yet, in its algorithmic reconfiguration of digital images, technical cognition restructures our perception of the world. Furthermore, if the objects which surround my body are predominantly screens, and the possible actions they reflect are to click, to scroll, to swipe or to share, then the screen image doesn't just modulate my mental images but begins to establish the terms of this possible action. As Jonathan Beller writes: "the screen/image … places perception and discourse in a feedback loop with capitalised machinery and makes these subject to algorithmic governance" (2016).

I will elaborate one further correlation between visual cognition and image processing before concluding this chapter, a correlation based not on their operation, but their materiality. "An animal forms an eye for itself" writes Deleuze, "by causing scattered and luminous excitations to be reproduced on a privileged surface of its body" (MacKenzie 2010: 25). Here Deleuze posits a fleshy consistency between the surface of the retina and all other corporeal surfaces, internal and external. In neuroscientific explanations of visual perception, cognition does not take place exclusively in the visual cortex, but begins in the ganglion cells lining the back of the retina. Conceiving of the retina as a privileged surface, essentially no different from any other in the body, and extending this to our understanding of the different privileges of the various layers and structures of the visual cortex highlights the *material continuity* through which the process of cognition occurs. Although, as Hayles writes of technical cognizers: "the material bases for their operations differ significantly from the analogue chemical/electrical signaling in biological beings" (2017: 25), a similar consistency exists in the circuitry of a camera. CCD and CMOS sensors are semiconductors, consisting of layers of silicon and silicon dioxide doped with various other elements to build conductive and resistive paths within them. The 'privilege' of an image sensor is the photosensitive treatment of its upper surface. Its substrate however is *materially identical* to any other integrated circuit or microchip. The standard material infrastructure for computational logic is now the same as that which enables machine vision. Trevor Paglen asserts that "what is truly revolutionary about the advent of digital images is the fact that they are fundamentally machine-readable" (2016). The shared silicon materiality of image sensors and logic chips is crucial in enabling machine-legibility: image acquisition and algorithmic decisions can occur in the same chip. Just as CMOS sensors have introduced on-chip amplifiers, any other logic operations can theoretically be built-in prior to readout. In contemporary instances of perceptual technics the interfacing of these two distinct materialities of cognition and computation is increasingly the aim.

The Cognitive Technology Threat Warning System (CT2WS, fig. 22) was a project developed

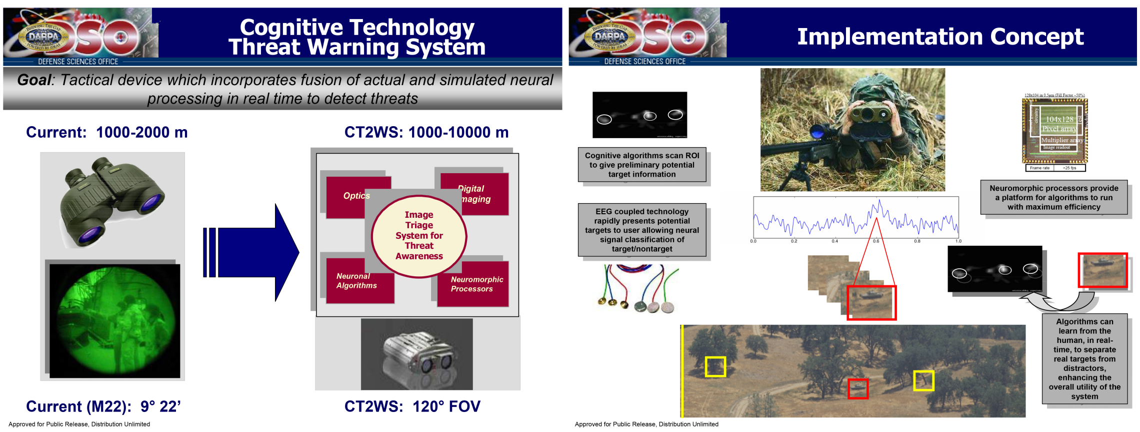

Fig. 22 Two slides from a DARPA presentation on the Cognitive Technology Threat Warning System.

by the NIA (Neurotechnology for Intelligence Analysis), a subdivision of DARPA, the scientific research and development wing of the US military. In 2007 it sought to connect digital imaging systems and human form perception, essentially short-circuiting cognition. The proposal was for a digital imaging device with a 120 degree field of vision that could magnify up to a distance of 10km. The user, equipped with EEG sensors to monitor neural activity, would be displayed "cut-up sections of such images flashed before the eyes at a rate of ten images per second" (Hansen 2015: 56), in a manner that prefigures the image captcha mosaics since used by Google. The NIA estimated that threat evaluation of each of these image sections would occur in the brain in less than 250 milliseconds, and that a machine analysis of the EEG signal would record these potential threats. So, in spite of Berardi's insistence that "the time necessary for psychological and bodily elaboration cannot be shortened beyond a certain point" (2015: 44), our nonconscious synapse-response to an image stimulus *can* be operationalised within a machinic rhythm. The CT2WS system is emblematic of what Tony Sampson describes as the "effort made to put neuronal interactions to work below the threshold of conscious cognizance" (2017: 48). The solution to the difficulty of algorithmically imitating form recognition was simply to outsource this function to human visual perception.

> Here the priority of image and user is fully reversed as the human sensorium becomes an input device for the command-control function of computation, while the human body becomes an algorithm's avatar. (Beller 2016)

As military tools continue to trickle down into consumer technologies, a future in which the cam-phone-puter is wirelessly connected to its user via EEG is not inconceivable. But even in the considerably more mundane case of current consumer camera use explored here, we can see how the instrumentalisation of the micro-temporal latency of digital image production via codecs and processing algorithms has the potential to preformat our visual experience, or as Hansen puts it in the broader context of twenty-first century media: "operate directly on that exterior sensible field before it affects our cognitive-perceptual system" (2015: 195). The intervention of image processing algorithms between sensor and screen make the camera capable of pre-constructing perceptual experience in advance. This raises the question of whether it is possible to account phenomenologically for an instrument that is already coded to prefigure neurological cognition. Digital image processing is explicitly designed to endear itself to human visual perception, its synthesis of early vision allows its imagery to appear as already embodied in perception prior to being seen. While in actuality the digital image is a meticulous algorithmic construction, a computational drawing that takes the photonic environment as just the basis of an image that is subsequently redefined as that which our eyes like to see. The digital camera masquerades as a transparent and passively representative instrument, but in fact consists of numerous opaque technicities that combine to present an image so psychophysically optimised that we struggle to distinguish it from our unmediated experience of the real. If we unquestioningly accept its noise-reduced, edge-enhanced products as the objective visual truth they purport to represent then, in the moment of reviewing (and consuming) our photographs, is 'early vision' not outsourced to the post-optical processes that precede the image? And do we, as a result, internalise the characteristics of the digital image as objective physical facts? In the intra-action between camera and user, is our imagination now manipulated by images algorithmically designed to appeal to it? The images produced by consumer cameras are encoded with the cognitive equivalent of confirmation bias.

Reduction of the Infinite

Considered as a holistic technical ensemble then, the digital camera can be conceived as a transducer that is contingent on its photonic and technical environment and affective in psychophysical and neurological space. In spectral, spatial and temporal terms this transduction is reductive, characterised by processes of filtering, averaging and limiting. Perception, according to Bergson, is constituted by exactly such reductions: "these are the trillions of exterior oscillations that the vision of colour condenses in our eyes, in a fraction of a second" (Lazzarato 2007: 97). In mediating photonic space for human perceptual faculties, the technics of the camera directly and repeatedly imitate physiological processes continuing the trend identified by Hansen in which "complexly embodied human operations have been fundamentally displaced in a world of microtemporal computational media" (2015: 26). Physical optics are extended by post-optical informatics which invisibly predispose themselves to our sight through perceptually targeted processing algorithms. While displacing corporeal perception, the digital camera also reifies physiological qualities within its technical elements. In the context of the consumer camera, machine vision aspires to and emulates, is addressed to and exploits its user's psychophysical limits.

Understanding sensor and screen as distinct technical individuals, performing separate transductions, enables us to perceive the expansive potential of the sensor, its capability to image a photonic extensity to which we have no access. Lazzarato describes the aspiration of electronic imaging as:

> a mechanics produced by human understanding that brings us a little closer to the real continuum of matter, allowing us to penetrate a little more intimately into perception's relation to the fabrication of images through time (2007: 120).

The tragedy of current digital image technologies is their precise failure to bring us closer, but rather to preclude us from experiencing the extensity of vibrations that constitute our photonic environment. This potential is instead discarded by a double filtering of photons: an infra-red filter (fig. 23) limits the sensor to the visible range, while a Bayer filter imitates retinal colour separation. For Panofsky, perspective enabled "the construction of the infinite within the limited field of perception" (Pasquinelli 2017: 290). Conversely, the digital camera reduces the infinite to a subsection of our already limited perception. The control enforced upon the spectral and chromatic operation of the sensor thus serves to reduce the discontinuities with, and increase the simulation of, physiological perception. In short, the new materiality of photography is shrouded behind a technical implementation of an anthropocentric perspective: one that both defers to and deceives human visual faculties, a reinforcement of perceived wisdom in the face of a demonstrably more complex physical reality. Perhaps we already inhabit the photographic future imagined by David Claerbout:

> Instead of choosing how we want to see the world, we will see the world the way it wants to be seen by us. There will be a perfect equivalence between our gaze onto the world and the signals emanating from it. (2016)

Image sensors are of course not confined to consumer technologies. Their genesis and concretisation is deeply entwined in particular with the photographic demands of space telescopy, as demonstrated in James Janesick's (2001) comprehensive technical account of the CCD. Their applications include several decidedly non-anthropocentric "hostile environments where high levels of radiation are encountered (e.g., outer space imaging applications, particle detection used in beam colliders, nuclear weapons use, plasma physics)" (Janesick 2001: 721). However, a dynamic exists between such applications and the sensor's consumer functions that is similar to that articulated by Kittler between super-computers - "the number crunchers" - and the ubiquitous desktop computer:

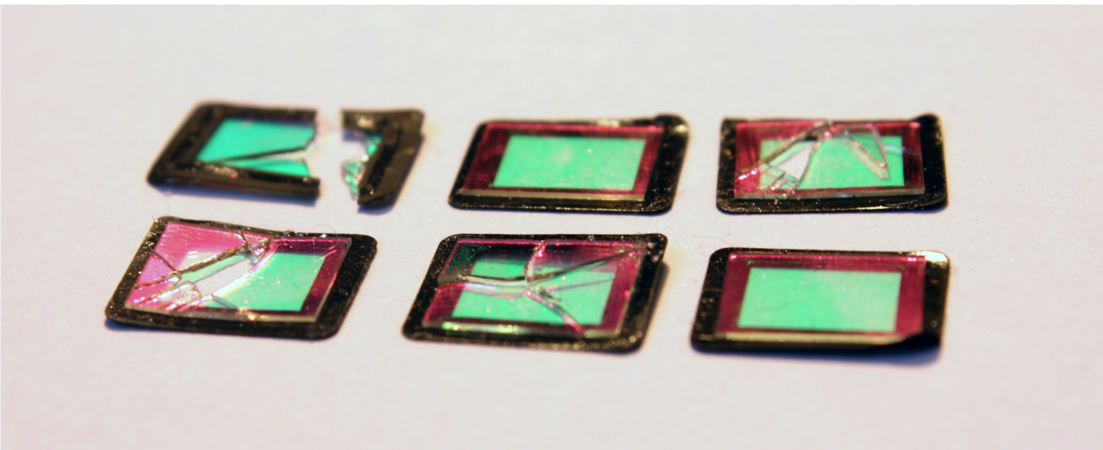

Fig. 23 Infra-red sensors removed from six image sensors.

> In the interest of the well being of so-called 'end-users' these machines have very consciously been restricted to applications that work with a finite number of elements (2006: 47).

The simulation of and optimisation for the human visual system realised by the perceptual technics of the camera serves to confirm the inaccuracies of our psychophysiological world-view. While the ability of the sensor to reveal that which lies beyond human perceptual limits is guarded for scientific research within realms of privileged access. Our visual experience is defined between red and violet, a fraction of the portion of the electromagnetic spectrum now understood as light. If once "X-rays proved definitively the limited nature of human vision" (Henderson 2009: 140) then could the image sensor serve today to mediate a vast and widely available expansion of these limits?

> The point … is not to refuse the technification of sensibility nor to bemoan our dependence on computational microsensors for access to it, but rather to embrace both in the service of a different outcome: the broadening of human experience to encompass a greater share of the microsensible domain. (Hansen 2015: 202)

To open our conception of the visual to the unfiltered, unprocessed image captured by the sensor, devoid of noise reduction and other perceptually addressed technics, would be to renounce the visible spectrum as defining the bounds of opticality, to realise the location of our sight within a physical system which exceeds us. As Zylinska writes: "the introduction of that inhuman perspective" could "liberat[e] vision from the constraints of the embodied human eye" (2017: 101). In the absence of smoothing algorithms, micro-spatial variations in chrominance would presumably mingle with the stray charges (noise) in the camera circuitry (fig. 24) revealing a chromatic micro-mosaic mutually constituted by the intra-action of the apparatus with its photonic environment. Such a media phenomenological image might be akin to what Crary describes as the "granular fluctuations of retinal luminosity" (2014: 127) we experience with closed eyes or in low-light. It would privilege neither photonic or instrumental reality nor human perception but would rather acknowledge that images are produced only in the entanglement of the observed object and the agencies observing it (Barad 2007: 114). We could posit such a shift as a move from the anthropocentric to the anthropo*technic*.

Zooming in on the gap between sensor and screen reveals an informatic intervention in image production, enabling an understanding of the camera as neither transparent nor objective but rather as an inscriptive apparatus, a writer of images. It is unsurprising then that the conflation and confusion Derrida observes between text and speech similarly pervades our relationship with digital images. "Representation mingles with what it represents to the point where … one thinks as if the represented were nothing more than the shadow or reflection of the representer" (Derrida 1976: 36), and elsewhere: "writing, which should only be an "image", usurps the principle role" (Derrida 2004: 22). This analogy between digital image and written word evidences our affinity for the apparent stasis and reliability of the immutable representation, sign or image, which Barad refers to as "the asymmetrical faith we place in our access to representations over things" (2007: 49). In the digital camera, representation is produced by a concatenation of discrete perceptual-targeted processes entirely opaque from the user, concealed behind a screen we are encouraged to treat as transparent.

The 'asymmetrical faith' in the digital image is not only a result of the "ease" which Derrida speaks of as being "curiously, but as usual, on the side of technical artifice and not within the inclination of the natural movement thus thwarted" (1976: 35) but also a product of the camera's intentionally 'pleasing' misrepresentations of its photonic environment. The camera behaves with respect to sight in the same way that Derrida conceives of writing as "lead[ing] to nothing less than the 'overtaking' of speech by machine" (1976: 79).

Writing in 1979, Ihde describes a future in which the technical development of optical instruments outstrips naked perception.

> In short, I begin to accept, literally, the instrument mediated world through what might be called an *instrumental realism*. The instrument constituted world becomes the 'real'

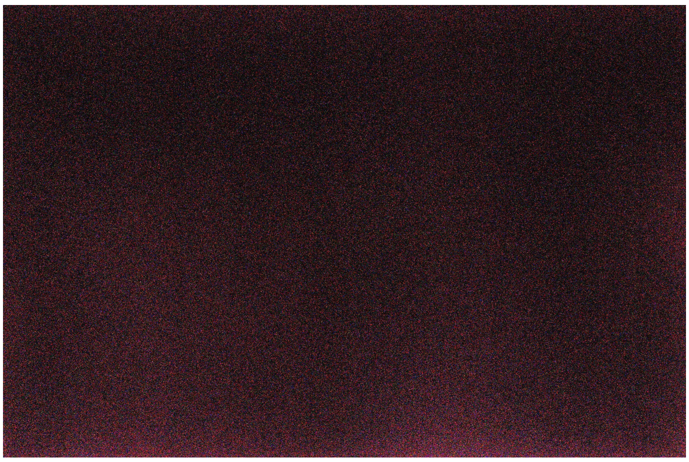

Fig. 24 Dark current image from a Canon EOS650 (22 minute exposure with lens cap on)

> world. Not only do I forget the mundane world, but it begins to be downgraded. (Ihde 1979: 46)

From a contemporary perspective it is hard not to see this passage as more prescient than hypothetical. Our photonic environment has become understood via the mediating circuitry of a device which operates in an avisual, informatic, and computational mode. Our sight is subjected to a post-optical reconfiguration in which technical codecs precede human cognition. If, as Berardi says, "the technical mode in which we receive and elaborate images acts upon the formation of our imagination" (2015: 41) then we are now at risk of losing the perceptual basis of our imagination to pre-determined industrial abstractions inscribed in the hardware we surround ourselves with. This highlights the limitations of traditional phenomenological analysis with regard to the contemporary technics of vision. For, in spite of the digital camera's awkwardness as an embodied instrument, its 'neurological memes', the algorithms with which it restructures the image, penetrate visual cognition, altering our optical expectations and the value that we place in the visible: "algorithms have the power to institutionalise perception" (Cubitt et al 2015: 254). Just as for Simondon, information is that which imparts a form to a technical individual, imagination might be understood as cognitive forms that result from the perception of images, a perception which is preceded and reconfigured by technical cognition. As Hayles writes "we need to recognise that when we design, implement and extend technical cognitive systems, we are partly designing ourselves" (2017: 141).

Simondon, however, doesn't distinguish between subject and technical instrument in this way. For him "knowledge is not grounded on the side of the subject any more than it is on the side of the object" (Coombes 2013: 7) and all such processes, whether human or technical are operations of individuation: transductions. The formation of our imagination then is both analogous to and profoundly impacted by the concretisation of the image sensor. Subjectivity is evolving not just in parallel to, but in entanglement with the evolution of its own technical individuality.

In her discussion of embodiment, Barad takes up an example from Niels Bohr which is almost identical to Ihde's example of the dentist's probe (or Merleau Ponty's blind man's cane). Barad, however is expressly not interested in "making a point about the nature of conscious subjective experience, that is, about phenomena in the phenomenologist's sense", but rather about the "inherent ambiguities of bodily borders" (2007: 155). She refuses to accept the edge-enhanced vision of the world propagated by digital images in which subjects, objects and instruments are discrete and separable, instead positing a mutually constitutive intra-action between knower and known, observer and observed, one in which the boundaries of human subjects, technical apparatus and observed reality are flexible and can only be understood or defined in the knowledge of specific and momentary phenomenal interactions between them. In Barad's example of pre-natal ultrasound: "the piezo-electric transducer is the interface between the objectification of the foetus and the subjectivation of the technician, physician, engineer" (2007: 204) and, I might add, that of the mother too. The transductive nature of subjectivity, our individuation, is enacted through the technical transductions of the instruments we use, which simultaneously serve to objectify our photonic environment and subjectify their users.

What then are the consequences of a technics that expressly seeks to endear itself to our sight? Have we begun to imagine our environment through the codecs by which we image it? And if so, are we able to distinguish our own agency from that of the camera, or is our subjectivity as constructed by the perceptual technics of the camera as by our own physiology? To address these questions we must first understand how subjectivity is produced and the role of both images and media in contributing to it. To do so, in Chapter 4, I will outline a post-Operaist theory of the production of subjectivity before analysing how these social processes are impacted by the perceptual technics described here and the post-optical, informatic economy of the twenty first century.

Chapter 4

Subjectivation and the Digital Camera

In the realm of the codec we can
no longer separate aesthetics
from political economy

Sean Cubitt

In this chapter, I will address the second half of my second research question: to what extent does the camera's technical architecture model contemporary subjectivity? The digital camera, particularly in its current wirelessly networked form, is only a recent entrant in a long history of technologies that have tended to break phenomenal continuity or social community into discrete chunks of data. Its computational reconfiguration of our photonic environment was preceded by a pervasive modeling of conscious thought as computation and society as a network. Seb Franklin emphasises the long history of this analogy between digitality and society, citing Charles Babbage's conception of the "modularised body of the individual worker and the divided body of workers … as fundamentally interchangeable with the idea of a digital computer" (2015: 23). The architecture of the camera should therefore be understood as symptomatic of and contributing to a wider cultural logic, rather than being solely responsible for it. As Franklin puts it: "thought and practice relating to the management of society have become imbricated with but not simply determined by particular technologies" (2015: xiv). The tendencies observed in the perceptual technics of the camera: to enhance edges, reduce noise, and filter frequencies, to extract, enumerate and encode are not only evident in the digital image, but are also evident in algorithmic socioeconomic analysis and the programmed management of populations.

The camera is no longer merely a device for the refraction of light onto a photosensitive substrate. This momentary acquisition of light information, which for more than a century was the sole purpose of the photographic apparatus, is now just the trigger for a multitude of computational calculations. The graphical suffix of the photo-*graphic* process has been enormously complexified and obfuscated by its algorithmic automation. Furthermore, in its most common current consumer usage - the smartphone - the camera exists as one among many functions of a device we use to navigate, communicate, shop, organise, broadcast, listen and so on. Not only is camera hardware integrated technically into the apparatus but, perhaps as a consequence, images play an ever more central role in these multiple functions, all of which we perform computationally (and all of which perform upon us, also computationally).

Felix Guattari describes images as "constituting the seeds of the production of subjectivity" (1995: 25). My analysis above demonstrates that the imitation of human visual perception in the technical protocols of camera hard and softwares enables the digital image to act directly on imagination. Is this routine micro-management of the image not therefore simultaneously constructing our own self-image? In a time of rampant social media usage, it is evident that we are explicitly depicted, objectified, invested in and subjectivated by images. But, in the same way that the digital camera's human-address accounts for only a fraction of its internal technics, are these acts of performative auto-subjection merely the front end of a subjectivating entanglement with camera and image, the majority of which occurs beneath human perceptual resolution?

To address these questions I will first introduce Maurizio Lazzarato's account of the production of subjectivity in contemporary capitalism. In developing his thesis, Lazzarato draws extensively from the writings of Guattari, but whereas Guattari is more focused on the psychoanalytic affects of subjectivation, Lazzarato analyses instead the external functioning of sign systems and machines that contribute to this domain. I will demonstrate how the digital camera's semiotic construction of the image exemplifies these sign systems and machinisms, providing a detailed concrete example of Lazzarato's theory by applying it to post-optical visual culture. Thereafter I will outline how the image operates within what Lazzarato would describe as an economy of immaterial labour and cognitive capitalism, but with reference primarily to the writings of Jonathan Beller and Franco Berardi. Finally, I will propose a correlation between the architecture of the digital image and the production of subjectivity which develops the positions of Beller and Lazzarato by evidencing the digital camera's specific tendency to simultaneously reduce its subjects and objects to enumerable fragments.

The Production of Subjectivity

In *Signs and Machines*, Lazzarato (2014) discusses at length the role of semiotics and machinisms in the production of subjectivity in late capitalism. Lazzarato uses the term machinisms to include not only technical machines, but also social machines and the 'megamachine': a concept introduced by Lewis Mumford in which human, animal, and technical elements function together. Contemporary examples of this include corporations and welfare states. For Lazzarato, the production of subjectivity occurs today at the intersection of two often contradictory and yet simultaneous processes: social subjection and machinic enslavement.

Social subjection includes any process by which citizens acquire their individuality. As Lazzarato writes, it "equips us with … an identity, a sex, a body, a profession, a nationality … In this way it manufactures individuated subjects, their consciousness, representations and behaviour" (2014: 12). Subjection therefore tends to enforce differences, most importantly those between subject and object, human and machine. Subjection posits the subject as a unified entity "in relation to an external object of which the subject makes use … the individual works or communicates with another individuated subject by way of an object-machine" (2014: 26). The traditional conception of a photographer as an individual in control of the camera, who composes and captures images of an external and distinct reality, therefore conforms to this understanding of subjection.

By contrast, processes of machinic enslavement have no concern for the holistic unity of the individual. On the contrary they tend towards desubjectivation: breaking down the subject into molecular components, inputs and outputs. If "subjection produces and subjects individuals", then "in enslavement individuals become dividuals and masses become samples, data … The dividual functions in enslavement in the same way as the non-human component parts of technical machines" (2014: 26). Furthermore:

> not only is the dividual of a piece with the machinic assemblage but he is also torn to pieces by it,.. sensations, cognition, memory … are now components whose synthesis no longer lies in the person but in the assemblage or process (2014: 27)

In an essay discussing the relationship between Italian Operaismo and the Information Machine, Matteo Pasquinelli (2015) cites a little known and untranslated 1963 essay by Romano Alquati that prefigures the theoretical positions of Operaismo with regard to information and labour. In it Alquati identifies the worker as the source of what he calls *valorizing information* in the industrial era, defining information as "precisely all the innovative micro-decisions … that workers have to take … that give form to the product but also that give form to the machinic apparatus itself" (Pasquinelli 2015: 54-5). For Alquati, it is cybernetics which enables the knowledge and skill of the worker to *in*form (to give to form to) the machinic apparatus: "cybernetics recomposes globally and organically the functions of the general worker that are pulverised into individual micro-decisions" (Pasquinelli 2015: 55). Here already, in an essay grounded in the factory technics of industrial production, we see many of the tropes of machinic enslavement and the dividual subjectivity it produces.

Lazzarato traces the concept of machinic enslavement to Deleuze and Guattari who, in turn, borrow "explicitly from cybernetics … enslavement is the mode of control and regulation of a technical or social machine" (Lazzarato 2014: 25). Just as cybernetics posits methods of control applicable to both technical and social domains, in processes of enslavement no distinction is made between the human and the machine: "the dividual does not stand opposite machines … the dividual is contiguous with machines. Together they create a humans-machines apparatus" (2014: 26). In the context of a society that relies increasingly on processes of technical cognition, it becomes irrelevant whether the 'micro-decisions' of which Alquati speaks are made by people or algorithms, the two simply become interchangeable inputs. To apply this theory to digital photography: the perceptual technics of the camera fragment the user into the constituent elements of his/her visual physiology, before combining them with its own technical elements and image algorithms, producing a human-camera apparatus, or (visually) cognitive assemblage.

In Simondon's philosophy, the division of the technical object into ensembles, individuals, and elements concurs with this fragmentation of the individual by machinic enslavement. Although Simondon's thesis predates the term 'dividual', he already posited the machine as a threat to man's technical individuality.

> If man often feels frustration before the machine, it is because the machine functionally replaces him as an individual … man, disengaged from this function of the technical individual … can now become either organiser of the ensemble of technical individuals, or helper of the technical individuals … he plays an auxiliary role (2017: 78)

In Simondon's description subjection and enslavement coexist. Man stands "before the machine", in the position of subject to it as an external object, which simultaneously replaces his/her individuality: s/he becomes an auxiliary in a larger technical ensemble. Machinic enslavement combines an ability to divide the individual both perceptually and physiologically into distinct sensory, motor and cognitive facets, with an ability to recompose these facets with those of other dividuals, technical processes and other information, creating what Mumford calls a 'megamachine'. Machinic enslavement therefore operates at scales over and above the individual (those which Simondon would refer to as higher-level ensembles or Lazzarato as social machines) and simultaneously at scales below and beneath the individual, at the pre-individual, perceptual level of Simondon's elements. In Lazzarato's words it "activates both much more and much less than consciousness and representation … much more and much less than the person, the individual, and intersubjectivity" (2014: 30).

For Lazzarato, these two processes of subjection and enslavement are mobilised by equally contradictory semiotic regimes. Subjection speaks to the individual through semiotic regimes that "produce meaning, significations, interpretations, discourse and representations" (2014: 39) primarily language, but also - and increasingly - images. Meanwhile, machinic enslavement "functions based on asignifying semiotics" which are nevertheless able to "produce operations, induce action, and constitute input and output" (2014: 39). Subjection might therefore be said to appeal to the intellect, to the conscious mind, and to the ego, while enslavement is more invasive:

> it employs modeling and modulating techniques … It takes over human beings from the inside on the pre-personal (pre-cognitive and pre-verbal) level, formats the basic functioning of perceptive, sensory, affective, cognitive and linguistic behavior. (2014: 38)

Applying Lazzarato's distinction between signifying and asignifying semiotics to my analysis of the perceptual technics of the camera enables us to see how it simultaneously enacts processes of subjection and enslavement. The representational image content reproduced on the screen operates in the mode of subjection. The selection of photographic content is one means by which we are continually constructing and reconstructing our identity. Meanwhile, the invisible perceptually targeted operations of the camera are structuring our responses by modifying what Lazzarato refers to as the "sub-representational reality" (2014: 37) of the image. The externalised synthesis of early vision, present in the camera's algorithmic technics, creates what Simondon refers to as "the coupling of man to machine" which "begins to exist from the very moment when a coding common to both of these memories can be discovered" (2017: 138). Applying this to informatic photography, human memory becomes formatted by the schematic memory of idealised images embedded in the camera's processing circuitry. According to Simondon, "the subject consists of the permanent interweaving of pre-individual elements and individuated characteristics; moreover, the subject *is* this interweaving" (Virno 2004: 78). The camera now operates at the level of these pre-individual elements, enabling visual cognition to take place in a hybrid of algorithmic and neurological space. As a result, its image processing functions behave in the manner with which Lazzarato writes of machines in general:

> protocols, diagrams, graphs, and software lose their objectivity and become capable of constituting vectors of proto-subjectivation … they suggest, enable, solicit, prompt, encourage, and prohibit certain actions, thoughts and affects or promote others (2014: 30).

Although there is not space here for an in depth analysis of the operations of images in contemporary social media, it is worth noting that the co-existence of subjection and enslavement is particularly apparent in this context. For while we consensually participate in these induced actions of networked auto-subjection, human attention is harvested as desubjectivised data to be subsequently instrumentalised as a global scale marketing apparatus. There is perhaps no more emblematic example of Lazzarato's concept of enslavement than this fragmentation of the individual into a sequence of desires, behaviours, tastes, purchases, viewing statistics and geo-locational habits then used to construct a series of social machine-networks able to directly, and imperceptibly, target those same faculties. As Lazzarato describes it: "the information concerns dividuals whose profiles, composed of the convergence of data, are mere relays of inputs and outputs in production-consumption machines" (2014: 37).

Applying Lazzarato's concept of machinic enslavement to the digital camera, we reach a similar conclusion to both Flusser, who described man as a "functionary" of the camera, and Beller, who asks, in the confrontation with the programmable image, "has the bios been sub-routinized by the program of the camera?" (2017). The equation of human perception and response to machinic input and output reduces the living: the *bios*, to what computer scientists coincidentally abbreviate as BIOS: a basic input-output system. The image-information produced and displayed by the camera is structured and distributed by machinic logics predicated on the reduction of all events to numeric information. Human image response becomes less a matter of conscious individuation than an informatic input into a global database, not so much subjective as calculable, or as Beller succinctly puts it: "we may see images, but the AI practices optimisation" (2017).

We can therefore include the camera as an example of what Lazzarato calls "humans-machines systems" in which every operative element, whether human or technical, or as he puts it "the component parts of all work can be expressed in terms of information" (Lazzarato 2014: 29). Everything becomes quantifiable as data, and a correspondence is therefore produced between sensory and informatic signals. This strength of asignifying semiotics identified by Lazzarato, is also emphasized by Latour: "it is hard to overestimate the power that is gained by concentrating files written in a homogenous and combinable form" (1990: 26-7). The asignifying semiotics of the digital produce a monetary equivalence between the camera as a traditional industrial commodity, its images, and our attention. Whether subject or object, hardware or code, material or temporal, all become capitalisable along the same lines. Lazzarato and Guattari's concept of asignifying semiotics underlines therefore the pivotal importance of the image sensor in the attention economy. It is the technics of the sensor that enables the continuous wavelengths of our photonic environment to be restructured as discrete, linear data in the mode of asignigying semiotics. As a result, the position of the photographer as individuated subject is undone by the very mechanism of photography.

Before returning to this relationship between the digital image and dividuated subjectivity, I will elaborate how the digital image operates as a commodity and how, while structuring pictorial space as a distribution of pixel values, it simultaneously structures human attention as a vector of valorisation.

Image as Commodity

My characterisation in Chapter 3 of the camera as an inscriptive interface between the objectification of our environment and our own subjectivation has ramifications for how we understand the dynamic between capture and display, image-writing and image-reading, photographer and viewer. In Derrida's terms we could describe this as "the gap … between the agencies of sender and addressee" (Bennington 1993: 55).

> The act of writing is from the first divided by this complicity between writing and reading… and blurs at the same time the activity/passivity (or production / consumption) distinction that underlies the usual understanding of writing. (Bennington 1993: 53)

For Derrida, the writer is necessarily the first reader. The act of writing, by definition, constitutes a self-reflexive act of consumption - and so too the act of photography. This consumption is built-in to digital camera hardware in the process of image review.
In the contemporary act of image-writing we are more the addressee of the image-text than its sender. The human-address of the screen acts as an economic address to its first consumer. The reduction of latency in photographic technics discussed above hastens the image's realisation as a commodity. While the encasing of the camera within a wirelessly networked portable computer hastens the realisation of this commodity value in the share-value of the platform on which the image is then distributed.

Jonathan Beller has written extensively about the commodification of images and industrialisation of vision achieved through the transition from manual to sensual labour.
In a recent essay titled *The Programmable Image of Capital* (2016a), he expands on Marx's general formula for capital: M-C-M' to include images. In Marx's formula, M stands for money and C

for commodities, while M' denotes that the value of the money made selling the commodities is greater than the value used to produce them, hence surplus value is produced in the transaction as a whole. As Beller writes, "It is the worker's unpaid labour that provides surplus value to capital and thereby creates the increase from M-M' during the cycle of commodity production" (2016a). Beller rewrites this formula for the era of computational capital as M-I-C-I'-M', where M is still money, but C is now code and I image. In this model the object-commodity of industrial society has been replaced by the encoded image, symptomatic of what Beller describes as "the shift from the paradigm of the factory to that of the screen-based social factory" (2016a). Within the production cycle of this social factory, "I-C-I' indexes the movement between appearance, praxis and digital informatic substrate, as when, for example, one uploads an image" (2016a). This action of uploading images causes them to proliferate and to accrue attention, hence I' is greater than I. It is this proliferation which produces surplus value, allowing M' at the end of the formula to outweigh the M which begun it. Beller's formula hinges at C: the moment the image is encoded from two dimensional pictorial space into linear alphanumeric space. As I have shown, this happens at more than one juncture within the camera and is subsequently repeated as a by-product of the uploading process. This C, which Beller uses to stand for code, could also be used to refer to *codecs*, the algorithmic vehicles which produce the image as code and hence simultaneously as commodity. The C might also then stand for *compression*: a universal attribute of such codecs and moreover a pre-requisite of the uploading protocols of all social media platforms. Understanding C as code, codec and compression reveals in more detail the mechanism by which surplus value is produced through images. It is not only through the unpaid labour of sensual consumers but also through the algorithmic and perceptually targeted reduction of information within the image. Simondon's understanding that "there is no common measure between the quantity of information that is effectively interesting and significant for the subject, and the quantity of information that is technically employed" (2017: 116), has been actively instrumentalised as a value-producing mechanism in the circulation of images in the social factory.

In the attention economy, the raw camera image has intrinsically less value than its compressed counterpart: it is the reduction of visual information that enables the proliferation of images and the creation of surplus-image-value. To bring an understanding of the transductions in the contemporary camera to this redrawn formula of capital, reveals how the reductions of spectrum, colour gamut, and resolution discussed in Chapter 3 directly contribute to the camera's operation as an instrument of capital: a device for the creation of surplus-image-value. We can then observe two contradictory tendencies in the ongoing commodification of photography. On the one hand, the camera and its components, as traditional object-commodities, are driven towards ever higher resolutions as a means of reinforcing the narrative of progress and guaranteeing the obsolescence of the previous model; while on the other, the encoded digital objects they produce are compressed to minimise required server space and maximize revenue. Intervening between these opposing trends is a third economy peculiar to digitisation, that of compression codecs: the ability to reduce the millions of pixels captured in camera to a few hundred kilobytes of data without any perceptual loss of quality is perhaps now the most highly prized commodity in the image economy.

This shift from manual to sensual labour and from factory to social factory implies a change in the nature of the commodity, from a tangible object to a sensory experience. But as Beller points out:

> it was a mistake to imagine that because the industrial object was comprehended as a commodity, the commodity form is necessarily an object … Industrial production created commodified objects to be sold at markets, while distributed (digital) production creates derivative "objects" … to be sold on attention markets (2016a).

Seen from the perspective of subjectivation, it is not the dematerialisation of the object-commodity which is the biggest shift, but the transition of commodity value from object to subject. In the attention economy, or what Jodi Dean describes as 'communicative capitalism', "communicative exchanges … are the basic elements of capitalist production" (2005: 56). And in the communicative exchange of images, the human-camera assemblage replaces both the worker and the product. Beller does note that human subjectivity was already commodified in the traditional form of labour, but, in the factory, that labour always produced an external saleable object. In the social factory it serves only to increase or perpetuate the value of human subjection. As a result, if we internalise the logic of the attention economy, our own self-worth becomes attached to and constituted by the images we exchange.

When viewed in combination with the increased perceptual technics in contemporary smartphones, the camera acts as a shop window display: an instrument of visual merchandising which reduces everything our eyes see to potential commodity status. "Entering through the eyes, these images envelop their hosts, positing worlds, ... utilising the bio-power of concrete individuals to confer upon their propositions the aspect of reality" (Beller 2003). In Beller's eyes, we no longer judge the image according to its likeness with perceptual experience, but rather judge experience by whether it lives up to *its image*. The image has truly usurped the principle role. Physiological vision becomes a means of auditioning physical reality before capturing it *in camera*. This term, whose etymology is the legislative Latin for 'in private' is redefined by contemporary smartphones as the technics of personal publicity. If we consider the camera as a development of the manual imaging technologies of drawing, painting and printmaking, then the subjectivity of its users has mutated from a creative observer-interpreter of physical reality, to near passive consumer of images pre-ordained by an apparatus and the social norms constructed around it.

The grammatologies discussed in Chapter 3, the gridded lattice, shift register, matrix-addressing system and frequential analysis of image data, can be understood therefore as commodity architectures par excellence. These technical structures and processes: the fragmentation, encoding, and abstraction of visual space and temporal experience might be the most efficient value producing systems ever proliferated by capitalism. They sample from the Bergsonian flow of image-time in a manner so effective that we have come to equate them with the events themselves: 'photos or it didn't happen'. Beller speaks of contemporary media companies as "schemas for the expropriation of value produced by the users (and therefore the used)" (2015: 12), a formulation that also applies to the digital camera. The asignifying semiotic grammar of the digital image is that of the commodity: mobility, immutability,[1] and instantaneity are the prerogatives of its technical protocols.

> In every sphere of human action, a grammar establishes limits that define a space of communication. Today the economy has become the universal grammar penetrating every level of human activity. Language is defined and limited by its economic exchangeability (Berardi 2015: 320).

The perceptual technics of the digital image no longer merely compress the signal in order to conserve broadcast bandwidth or server space, but now extend to the economisation of the sensorium as a mechanism of value production. Neurological signals - thoughts - become entangled in and programmed by an implementation of economic logic masquerading behind an automation of photography. By rendering our visual engagement with the world around us as nothing more than what Beller describes as "bankable events" (Beller 2015: 12), the digital image commodifies sight itself and our responses to that which we see. In the ability to affect and inability to render those affects as anything other than a numerical (which is to say monetary) difference, the camera's transducers fail the transductions they engender in us.

The camera has evolved into a technical element in a global-scale extraction ensemble whose sole purpose is to wring value from every act of its subject's waking lives. The image sensor, by micro-temporally packaging images into asignifying semiotic code shifts the commodity of the photograph from its physical materials to its perceptual moment. A transition that moves from

[1] See Latour (1990) for an account of the importance of mobility and immutability in inscriptions and commodities.

the spatial dimensions of an image: its scale, print quantity, and distribution, to the temporal dimension of its exposure to our eyeballs. As Crary writes:

> The term 'eyeballs' for the site of control repositions human vision as a motor activity that can be subjected to external direction or stimuli. The goal is to refine the capacity to localize the eye's movement on or within highly targeted sites or points of interest. The eye is dislodged from the realm of optics and made into an intermediary element of a circuit whose end result is always a motor response of the body to electronic solicitation. (2014: 76)

The optimisation of the outputs of sensor and screen for human perceptual physiology: the technical cognition encoded in the camera's algorithms, enable the incorporation of eye and brain, sight and thought, into an electro-technical system. The post-optical technics of the camera leverage both vision and cognition into a machinic process which Tony Sampson (2017) refers to as 'neurolabour'. The neurological and psychological spaces of subjectivity are interpenetrated with machinisms by which human image responses are extracted and enumerated, abstracted and monetised.

The Pixelate Dividual

The electronic capture and digital encoding of photons accelerates the image's appearance as, and circulation in, commodity form. From a technical perspective, it is the gridded (con)formation of image sensor and screen that enables the image to be enumerated and exchanged by the same network cables and protocols as high-frequency stock trading. The primary function of the grid is to fragment the unity of the image according to a linear and sequential system. As Graham Harwood writes in his entry to the Software Studies lexicon:

> Digital cameras sample light from a particular position, that of the lens. This involves converting the continuous light we see to the discrete quantities of bitmaps … a process by which the world is chopped up into chunks that conform to those boundaries (2008: 215).

The digital camera therefore combines two distinct but interwoven means of structuring image-space: perspective and pixelation. Its monocular lens perpetuates the camera's history as an optical instrument which, for Victor Burgin, is "inseparable from the history of perspective" (Bishop & Cubitt 2013: 203). However to consider the digital camera only as an electronic instantiation of a previously mechanical apparatus ignores that which distinguishes it from its analogue predecessors: the grid. Although common in pictorial technologies since the Renaissance, it is only with the CCD that this grid is applied to the technics of the photography. This combination of cultural techniques provides an optoelectronic echo of the early history of visual media. Kittler's history of linear perspective begins with Brunellschi's painting of the Florence Baptistry, which for him marks the invention of "the camera obscura as a practical painting device". However, he continues, "this did not solve all the problems of linear perspective painting" because "the camera obscura only works in the real world" (2010: 61).

> The simple question for Brunelleschi's successors, therefore, was how to take the geometrical automatism of the camera obscura and transfer it to other media. … The problem was how to construct perspectival drawings on paper geometrically, especially when these drawings were pure fantasy (Kittler 2010: 61).

The gridding of the photographic plane introduced by the CCD replicates in optical microelectronics the solution to this problem first arrived at by Alberti, whose *fenestra aperta* Kittler considers "the ancestor of all those graphic user interfaces which have endowed computer screens with so-called windows" (2010: 62). If, for Kittler, Alberti's division of the visual field into a mosaic of windows becomes a "thousand-eyed Argos" (2010: 62), then image sensors are multi-million-machine-eyed icons made in its image. Where Alberti's innovation of gridding of the visual field enabled perspective to be calculated as a trigonometric function within a rectilinear system, thus, as Panofsky writes in his well known essay on perspective: "transform[ing] psychophysical space into mathematical space" (1991: 31), the gridded surface of the sensor enables contemporary cameras to compute the image according to an equally mathematical set of algorithms which calculate luminance and chrominance as frequency distributions across this plane.

Alberti's veil had two key effects, and both have parallels with digitisation. Firstly, it enabled the construction of imaginary or fantastical architectural spaces within the geometrical laws of optical reality. And secondly, the inscription of the camera obscura's projection onto paper increased its mobility, allowing these projections to leave the shaded confines of a darkened room and circulate in public. Similarly, in a contemporary era of picture-edited news and other Photoshopped realities, a constant blurring of the line between fact and fallacy has become a defining trope of the digital image, which also distinguishes itself by its mobility: circulating the globe encoded as sequences of discrete units. More important however, is the correlation between this technical coupling of monocular perspective with pixelation and the twin processes of social subjection and machinic enslavement that constitute the production of contemporary subjectivity.

Monocular perspective places an imaginary human (and, historically, white male) eye at the apex of a conical visual space. Just as perspective is a convenient technique for translating three dimensional space onto a two dimensional surface, it is also a technique for locating the subject within this space. Cubitt refers to it as "an apparatus" akin to language in that both allow "multiple places in which the subject can be placed" (2014: 212). In spite of the discrepancies with physiological sight outlined by Panofsky (1991), its success as a system of visually and geometrically ordering the world hinges on its successful synthesis of human vision. Before the invention of linear perspective "the totality of the world always remained something radically discontinuous" (Panofsky 1991: 44). Panofsky goes on to describe "the inability of antique thought to … distin[guish] between 'body' and 'nonbody'" (1991: 44). Perspective then is a visual technique that defines the subject as an individual, unified entity whose agency and mobility within the world are assured, distinct from, and active upon the objects and spaces that surround him. Just as processes of social subjection place "a subject in relation to an external object of which the subject makes use" (Lazzarato 2014: 26), perspective too "creates distance between human beings and things … determined by the freely chosen position of a subjective point of view" (Panofsky 1991: 67). By simulating an eye devoid of psychological subjectivity, perspective constructs a generalised individuality of the viewer that any observer can inhabit, producing a locus for what Crary has called "ocular possession" (1990: 127). As a result, it produces the scene itself as a commodity. As Cubitt writes, "perspective … constructed not only an ideal viewing position but also an ideological subsumption of the viewer into the subject-form associated with capitalism" (2014: 208).

Perspective produces the viewer as a holistic individual, or after Beller, an attentive labourer. Pixelation, however, acts upon the image in the same manner as processes of machinic enslavement, producing a dividual subjectivity. Although I am not suggesting here that pixelation alone causes dividuality, the extent to which its technics are now imbricated within the operations of contemporary media and the defining role these technologies play in our subjection confirms the considerable extent of their impact. Indeed, the similarity between a fragmentary subjectivity and a mosaiced image form is not merely superficial. The relation between the image as a whole and its existence as encoded pixel values also illustrates precisely Lazzarato's distinction between signifying and asignifying semiotics.

Lazzarato has little to say about images specifically, but, following Guattari, includes them in his semiotic system by categorizing them as "symbolic semiotics" (2014: 86), a subset of signifying semiotics, differentiated in that they do not have a fixed and universal meaning. Yet, in spite of their inability "to establish invariable and stable significations", images or iconic signs as he also calls them are able to "produce models of behavior which possess the force of example and the self-evidence of physical presence" (2014: 129). Lazzarato describes this as "the immanent power of im[age]-signs" (2014: 138). In short, images may rely on subjective interpretation to produce significations, but it is in this very act of interpretation that the image acts upon us: vision invisibly constructs subjectivity. As Guattari writes, "we are not in the presence of a passively representative image but a vector of subjectivation" (1995: 25). The image, in its screen-based human-address, can therefore be understood as a signifying semiotic domain, but the encoded pixels in which it is stored, and the algorithms that structure and re-structure them, conform closely to Guattari's category of asignifying semiotics.

For Guattari, these semiological dimensions both "trigger informational sign machines" and "function in parallel or independently of the fact that they produce and convey significations and denotations, and thus escape from strictly linguistic analysis" (1995: 4). This description aptly captures the relationship I discuss in the previous chapter between the psychophysical affect of the image and the camera's internal informatics by which it is structured. While asignifying semiotics evade human perception, they analyse, act on, modify and constitute the reality and representations of human experience.

> The simplest example of direct intervention is that of the microchip, where sign flows act directly on the material components … the signs function as the input and output of the machine, bypassing denotation, representation and signification, (Lazzarato 2014: 85)

Digital images are representations created by a non-representative semiotic regime. While they may signify and hold significance for us, their production and distribution occurs in informatics semiotic regimes to which we have no access, which Hayles, resisting the anthropocentrism of defining them as asignifying, has recently termed cybersemiosis (2018). In all instances of digital mediation we are communicating via cybersemiotic systems, or in Lazzarato's words, "we are of a piece with machines" (2014: 88).

Guattari distinguishes representations from operations, the former functioning symbolically, the latter diagrammatically. Applying this distinction within the technics of the digital camera, it becomes evident that the image is created diagrammatically by algorithms that construct the representation we assume to be objective. These cybersemiotic codecs operate not on the individuated characteristics of subjectivity, but directly on perception, which Simondon refers to as pre-individual physiology, they usurp the human gaze. Whilst maintaining the appearance of linear perspective familiar from previous optical media, Cubitt therefore says that:

> digital vision begins with a withdrawal of the eyes … implicated in a technical apparatus of which, however, they are no longer constitutive, demoted to the role of elements in a system of which they are no longer the centre (2014: 108).

Subjection presumes and reinforces a unified 'I', and perspective a monocular eye. But the technical and algorithmic processes of digital image production are akin to those of machinic enslavement, they operate at scales both above and beneath the I/eye. The eye itself is torn to pieces in the camera's simulation of its physiological faculties: RGB channels separated, luminance detached from chrominance, noise reduction from edge enhancement and so on. Just as for Alquati, "the functions of the general worker" in the factory "are pulverised into individual microdecisions" (Pasquinelli 2015: 55), inside the digital camera sight itself is fragmented into its constituents, each controlled at separate stages of image processing. Simultaneously, the subject I is engaged in an attention economy, becoming part of a machinic assemblage that far exceeds him/her: "a new attachment of the individual to an industrial world that exceeds the dimension and possibility of thinking the individual" (Simondon 2017: 119). The eye's biological unity within an 'I' is of less consequence than its contribution to the statistical data harvested from its operation inside a post-industrial network.

In outlining his discussion of dividuated subjectivity, Guattari uses the following example:

> When I watch television, I exist at the intersection: 1. of a perceptual fascination provoked by the screen's luminous animation which borders on the hypnotic 2. of a captive relation with the narrative content of the programme … 3. of a world of phantasms occupying my daydreams. My feeling of personal identity is thus pulled in different directions. How can I maintain a relative sense of unicity despite the diversity of components of subjectivation that pass through me? (1995: 16)

How might we redraw this example in the context of contemporary networked cam-puters? How has the relatively modest transformation of screen-based technologies in the 25 years since this was written changed the stakes? The perceptual fascination with glowing phosphors is perpetuated in the liquid crystals of mobile handheld screens. Cut loose from mains voltage, their hypnosis now acts upon our entire waking life. In addition to the recent proliferation of screens and their increase in resolution, there is clearly a shift in the degree of our exposure to such luminous animations.

Our relationship with the narrative content of current screen media is too complex to untangle fully here. But, as traditional broadcasters compete with social media for attention, the biographies and narratives of our social milieu become interpolated among fictional and documentary narratives on screen. Our implication as subjects is evidenced in the hardware: smartphones are now routinely equipped with sensors gazing out towards the world and inward on their user (and laptops only the latter), placing ourselves into a commodity relation with our own gaze. As Crary writes: "images are now produced and circulated in the service of maximizing the amount of time spent in habitual forms of self-management" (2014: 47). If, as Guattari insists, televisual consumption places us in a *captive* relation with its content, then in the social factory we become captive consumers of our own subjectivity. This process also further fragments personal identity as we strive to maintain status (market share) across rival and parallel platforms.

However, of Guattari's three facets, it is the occupation of human daydreams by televisual phantasms that the shift towards mobile and social forms of screen consumption has impacted the most. As Hayles describes our current situation:

> Human complex systems and cognitive technical systems now interpenetrate one another in cognitive assemblages, unleashing a host of implications and consequences that we are still struggling to grasp and understand (2017: 175)

For both Hayles and Hanson (2015) it is the ability of computational media to operate faster than and therefore precede cognition which is pivotal, exposing human perception, cognition and imagination to the realities (p)reconfigured by machinic temporalities If, as Guattari writes: "the polyphony of modes of subjectivation actually corresponds to a multiplicity of ways of keeping time" (1995: 15), then to what extent are these varying temporalities now dictated by intra-actions with both technical machines and social machinisms? Our captivation with and immersion within a milieu of digital images exposes human temporal perception to the numerous machinic time-signatures of the media environment amongst which the limit speed of human neurological sensation and response seem increasingly sluggish. Wolfgang Ernst describes the contradiction between our own lived experience of time and such technical temporalities as "an implosion of the phenomenological sense of the present into a myriad of differential timing processes" (2017: 9), while Hayles speaks of the "incommensurable timelines of human and technical cognizers" (2017: 155). This disjunction between media temporalities and human physiological limit-times is certainly not peculiar to the digital. As Ina Blom writes:

> Video times were not necessarily calibrated to our sense of time, the normal human perception of motion, in fact, they often did not even attempt to address human attention, but appeared to turn inward, privileging a series of properly machinic timescapes (2016: 101)

However, the perpetual micro-temporal storage of digital video in shift registers amounts to an imperceptible buffering of the present. This buffering breaks the continuity of the signal, replacing the liveness of broadcast video with what Ernst has called "the concept of real time" and therefore "dislocates the metaphysics of the pure present to a micro-deferred now" (Ernst 2017: 35). Time, as experienced in digital streaming, is no longer a continuous broadcast into which we can enter at any given moment and with which we are always in time, but a multitude of parallel temporalities, each of which simulates phenomenological time afresh for each user.

Just as digital video operates beneath human temporal resolution, the digital image operates microscopically - on the level of the individual pixel - within these timescales. Vision is now mediated by a microchip whose operation is governed by clocking frequencies in the mega-hertz range: a speed that allows cameras to redistribute all of the pixels within an image several times in under a second. The responses of our eyes' photoreceptors – the hypnosis to which Guattari alludes – is predetermined. Sight is formatted on a cellular level by a technics too fast to see. Not only are "images and information broken down into ever smaller units" (Beller 2016a) but time too is "fractalised, reduced to minimal fragments that can be reassembled" (Berardi 2015: 206). These temporal fragments are now so small that even a concantenation as complex as the readout and processing of a digital image described in Chapter 3 is routinely thought of as instantaneous. Within this continual assault on our visual, temporal, and self- perception, is it still possible for imagination to evade the time-clock of the attention factory? And does failure to disengage from networked screens then lock cognition in machinic synchrony with what Guattari decribes as "a mecanosphere superposed on the biosphere" (1995: 40)?

We might refer to a world pixelated in every domain and dimension: spatially and temporally, visually and aurally, in/dividually and socially: human sensations and relations are fragmented and abstracted as data. This peculiar effect of the digital can be understood as the reduction of all things: images, attention, time, vision, and cognition (to name but a few) to a universal cybersemiotic code, one which enables subjectivity to be enumerated, monetised and valued by the same mechanisms as objects. Cubitt describes this process with respect to the image:

> First, the object is abstracted, as image, commodity, or numerical; and second it is placed into relations of equivalence with all other abstractions by dint of the formal equality of every cell, frame or price with every other … and in digital imaging, it is no longer images that are exchangeable but their component elements, the pixels. (Cubitt 2014: 7)

The fragmentation of subjectivity can be drawn along similar lines: first, as workers, whose labour-time can be placed into relations of equivalence by dint of a mechanical equivalence of minutes, hours. And in the social factory, it is no longer individuals who are exchangeable but their dividuated sensations, opinions and desires. A correlation exists between the pixelation of images and the dividuation of the human subject, between the technologies with which we objectify the world and their subjectivation of us. A correlation that, for Simondon, exists in all technical mediations:

> The emergence of the object only occurs through the isolation and fragmentation of the mediation between man and the world … this objectivation of a mediation must have as correlative … the subjectivation of a mediation. (2017: 177)

The digital camera acts on this threshold: it intervenes between humans and our photonic environment, it embeds its protocols into our mediated communication and visual cognition. It impacts the production of a subjectivity that appears as a unitary whole whilst simultaneously dissolving and distributing fragments that are exchanged as data commodities. The capture of photons and their algorithmic embedding into cognition has become contiguous with the computational capture of human subjectivities as an inexhaustible economic resource. In the multiple intra-actions of contemporary photography it is not just the image sensor that is exposed to photons, but the photographer, who is exposed to the informatic and commodifying logic of the technics of capital. In the process, human subjectivity is extracted and abstracted as a bio-stimulus in a social machine whose sole purpose is accumulation elsewhere.

Conclusion

Embarking on this project I set out to address two questions:

1. How can the materiality and operation of image sensors be exposed through experimental practice?
2. How has the image sensor reconfigured our relationship with our photonic environment and to what extent does its technical architecture model our contemporary subjectivity?

The first of these questions is addressed by the three assays that comprise *Saturation Trails.* The methodologies used: infra-red lasers, hydrofluoric acid, and X-ray radiation establish an experimental, materialist vocabulary for the (over)exposure and excavation of the digital image via its hardware. This methodology is by no means comprehensive: it focuses on the optical operation of the sensor rather than its post-optical, informatic functions, on its physical materiality rather than its computational logic. However, it does provide digital precedents for practices which have previously tended to exist only in analogue film or video, and therefore updates an important thread of experimental art practice which interrogates the moving image via its media hardware.

By using a combination of photonic (laser, X-ray) and chemical (acid) methodologies, this project could also be understood as arguing that digital photography is *still photo-chemical*. This insight, while elementary from a technical perspective, is novel in the context of the current theoretical writing about both analogue and digital photographic practices. There is, on the one hand, a marked tendency among theorists writing about celluloid film to use the terms 'analogue' and 'photo-chemical' as if they were interchangeable. While on the other, in spite of Cubitt's writing on image sensor technics (2014) and the recent media ecological turn focusing debate on the physicality of digital hardwares, there remains a pervasive ignorance of the materiality of digital photographic capture. Looking back on the debates surrounding the advent of digital photography (e.g. Mitchell 1992), it sometimes seems that in all the theoretical noise generated by the disappearance of the negative, the loss of an indexical original, and the threat to photographic authenticity, writers and artists alike omitted to simply transfer their fascination with the matter of photography onto its new form. Contrary to both of these tendencies, my insistence here on the digital as merely another photo-chemical solution to producing a camera highlights the mineral continuity between silver and silicon and privileges the physicality of its components over its much-vaunted binary storage. This insight can therefore hopefully add to the critical mass now fast refuting the industry-induced illusion that the digital is somehow immaterial, while also providing a precedent for artists that the camera is not as impermeable as it might appear.

Through these assays I sought to create images that are not predestined by the camera, images that lie outside of its Flusserian programme. These images – of photons that exceed its capacity to enumerate, of processes which penetrate its substrate, and of frequencies that exceed its imposed spectral limits – all expose its underlying abstraction. The laser overloads the columns of the CCD, fracturing and exposing the microelectronic channels through which the image-electrons flow. Hydroflouric acid etches into this substrate, eroding the grid before short-circuiting the signal at its edges. X-ray radiation reveals the grain of the digital image and, in the apparent flickering between colour temperatures, its attempts to normalise this extreme spectrum within the psychophysical bounds of visibility. In all three assays the camera's rendering of damage into image affords a glimpse beneath the illusionistic surface of representation. The images produced are therefore what Flusser refers to as "informative, improbable images that have not been seen before" (2000: 37).

The videos produced in *Saturation Trails* specifically have the potential to be informative in, to contribute to, the field of contemporary video art, where the absence of experimental approaches to the use, misuse, and abuse of the digital camera is most palpable. For many in this field the production values and methods of cinema have been so thoroughly internalised that merely editing together footage shot at different resolutions can seem radical. The assays conducted here are intended to shatter the presumption of normative use of technological tools that has become an orthodoxy in contemporary art in general and video practice in particular. Rather than the camera recording an image of its visible environment, in these laboratory settings, the environment images the invisible constructions within the camera. In these moments of photonic excess, spectral extensity and chemical corrosion the imperceptible architecture of the image, what Marks refers to as "the non-perceptual forces that intervene in the process of semiosis" (2010: 6), are exposed. This is not an exposure in the usual photographic sense but one that burrows deeper into the sensor's sub-representative operation. Each assay should therefore be considered a "targeted intervention that makes visible and intelligible the operational logic of the machine" (Apprich and Rossiter 2017: 278). To expose these technics is to challenge the authority and assumptions embedded in the camera circuitry. As Azoulay writes, "in photography, as in any technology packed in a black box, the technique of the instrument is supposed to remain inaccessible to its users" (Azoulay 2013: 40). By accessing, revealing, and sabotaging these technics, the three assays form a critique of the technological limitations of digital photography. In combination with my analysis in Chapter 3, they reveal the image sensor to be a tempo-chromatic transducer: a device that distinguishes the photonic frequencies of its environment between the colours of the visible spectrum. They reveal its extensive photonic sensitivity, covering a spectrum potentially larger than that between X-rays and infrared, but whose colour gamut is restricted to a subsection of the sensible. In short, they reveal a component whose transduction of our photonic environment is reductive.

The assays of *Saturation Trails* refute these limitations, responding to what Zylinska describes as "the inadequacy of the rigid formulations and categories through which [digital] photography has traditionally been perceived and approached" and "proposing instead that it may be time to radically transform, rather than just expand, its very notion" (2017: 188). The laser and X-ray assays repurpose a component designed to quantify the *in*tensity of light across its surface as one that reveals the *ex*tensity of light beyond human sight. My role in the project is therefore akin to that described by Latour as "the dissenter", who refuses to take the apparatus for granted, instead converting "black boxes into a field of contention" (1987: 77). This dissent is levelled at the hardware of the camera itself and on its own terms, which is to say that it is a critique conceived on the basis of the image sensor's materiality and one that exposes its consumer form to the destructive potential of epistemic processes from its own development and early scientific use. In these assays the camera is posited not only as a visual technology but one, as Azoulay says (2013: 46), whose operation creates and limits political possibilities. There is therefore a correlation between the technical subversions of the camera's representational function and a circumvention of the political limitations which it enables.

This correlation between technics and politics is addressed by my second research question: How has the image sensor reconfigured our relationship with our photonic environment and to what extent does its technical architecture model our contemporary subjectivity?

My analysis of the camera's perceptual technics reveals in detail the reductions, abstractions and informatic premises that govern its transduction of our photonic environment. This is another key contribution generated through this research which has the potential to enrich the current debates in visual media theory. While its largely technical insights are by now very old news to those working in optoelectronics, in contemporary photographic and media theory there persists a reticence to get to grips with the operation of our media and cameras. This is perhaps most notable in Flusser, who, in spite of arguing vehemently for a detailed critical understanding of photographic technics, neglected to provide one. Also among the writing investigating recent technological applications of 'the nonhuman gaze', 'post-anthropocentric visuality' or machine vision systems, there seems to be little understanding of just how technically discontinuous digital vision is with biological sight, and of what the cultural impacts of the technicity of digital vision might be. For example in *Nonhuman Photography* Zylinska theorises the contemporary cultural importance of images which are neither *of* humans, taken *by* humans, or intended *for* humans (2017: 51), while never addressing the fact that cameras do not see *like* humans. My analysis in Chapter 3 shows that the technical individuality of the image sensor has little relation with anthropocentric vision, but rather is sensitive across a broad photonic spectrum. Conversely, the LCD screen directly targets human retinal physiology, while the image processing algorithms pre-format the image for cognition. Where Ihde speaks of a "trajectory towards the perceptual and a trajectory away from the perceptual" (1979: 36), in the camera I have identified the co-existence of both. The former, rather than operating transparently has become entirely opaque, while the latter, though present in its technics, is largely excluded from its operation.

Recalling Ihde's concept of an 'amplification-reduction structure' in media, the reciprocal amplifications to what I have characterised as the camera's reductive transduction of photonic extensity can be understood as follows. The camera uses retinally-targeted filtering and cognitively-targeted processing to amplify its continuity with embodied sight. It amplifies the image's conformity with our expectations and confirms our (sometimes mistaken) perceptual assumptions. In some of its technics it could even be understood as going further, for example as privileging aesthetics over objectivity. But, at its centre, *the camera functions to amplify anthropocentrism*. In arguing for the visibility of a spectrum that exceeds perception and for a parallel expansion of photographic practice, I am arguing for conceptions of both the photonic and photographic that reach beyond these norms. As Parikka writes, "after the usual spectrum of visibility has been evacuated from perception, what remains is a visual culture that registers as post-Anthropocene" (Kriemann 2016: 107). Beyond the specialised realms of astrophotography or satellite surveillance, the potential of this photographic trajectory away from the perceptual remains largely untapped.

The image sensor operates not just perceptually but also economically. Its grid breaks continuous wavelengths into discrete, exchangeable pixels, enabling the transmission and exchange of images by the same protocols and in the same network as all other numerical encodings. As Franklin writes, "the technical possibility of the digital computer is bound to a discrete, symbolic register that is far closer to written text than images" (2015: 111). Without the image sensor's ability to render photonic frequencies as code, images and light itself would evade computation and machinic extraction. The image sensor's current monopoly in mediating vision represents a Gutenberg moment for human visuality: "because of this optical consistency, everything, no matter where it comes from, can be converted into diagrams and numbers … what counts is not the capitalisation of money, but the capitalisation of all compatible inscriptions" (Latour 1990: 20, 29).

The perceptual technics of the camera captivate human attention whilst its economisation of vision places us into a commodity relation with our photonic environment. The concept of exposure so central to historic understandings of photography must be redefined in the context of the digital camera and the computational acceleration of the attention economy in which it has played a pivotal role. In the intra-action of digital photography the exposure of the sensor to photons is merely a prerequisite for the exposure of cognition to the extractive and accumulative logic of capitalist technics. As Beller puts it: "the very function of these mediations enacts the computational colonisation of the subject" (2016a).

The obscuring of image sensors within the sealed confines of cameras, phones, and other consumer electronics is just one example of the pervasive concealment of contemporary media from sight and of their functionality from widespread comprehension. Without understanding how these technologies operate we are unable to critique them, to propose alternatives, or to understand the ideologies and biases embedded in their design. The assays and analysis above expose the operational opacity of this semiconductor in order that we might begin to take account of it and the transformation of visual culture into informatic culture precipitated by its technics.

We live, according to Simondon, in a continual state of individuation, the impulses registered in our pre-individual sensory physiology accrete into the shifts of perspective that define our individuality. The digital image engages these pre-individual faculties and penetrates our cognition, we exist in entanglement with its protocols, we intra-act with it.

> Having become a machine in a mechanised world, [w]e can regain [our] freedom only by taking on this role and superseding it through an understanding of technical functions. (Simondon, 2017: 117)

My exposure here of the constituent invisibilities of contemporary visual culture follows exactly calls such as these from Simondon, Hayles and many others to come to a closer understanding of the decisive influence such technical functions have come to exert on our sensations, perception and cognition.

In a world where purportedly 'digital' solutions are indiscriminately applied across a vast range of technologies, to wilfully ignore the operative specificities of each is to concede control of the technics of representation and communication to the whims of technologists. This project aims to prevent this occlusion of technics from the understanding of those who use them and theorise them. By revealing image sensor architectures and analysing their operation I hope to bring this one component into visibility so that we might take account of its wider cultural impact across the numerous devices and applications to which it is now central.

Bibliography

Agamben, G. (2009) *What is an Apparatus?* Stanford: Stanford University Press

Apprich, C & Rossiter, N. (2017) 'Sovereign Media, Critical Infrastructures, and Political Subjectivity' in Bishop, R., Gansing. K., Parikka, J. & Wilk, E. *Across & Beyond: A transmediale Reader on Post-digital Practices, Concepts and Institutions*. Berlin: Sternberg Press, pp. 270-283

Azoulay, A. (2012) *Civil Imagination: A Political Ontology of Photography.* London: Verso

Azoulay, A. (2014) *Aïm Deüelle Lüski and Horizontal Photography*. Leuven: Leuven University Press

Ballard, J.G. (1993) *The Atrocity Exhibition*. London: Flamingo

Barad, K. (2007) *Meeting The Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*, Durham: Duke University Press

Beller, J. (2003) 'Numismatics of the Sensual, Calculus of the Image: The Pyrotechnics of Control' in *Image and Narrative*. Available here: http://www.imageandnarrative.be/inarchive/mediumtheory/jonathanlbeller.htm [accessed 24/10/2016]

Beller, J. (2015) 'Within the Image' in Nickolić, G. & Tatlić, S. *The Gray Zones of Creativity & Capital.* Amsterdam: Institute of Network Cultures

Beller, J. (2016) 'Informatic Labor in the Age of Computational Capital', *Lateral 5.1* (2016), http://csalateral.org/wp/issue/5-1/informatic-labor-computational-capital-beller/ [accessed 17/10/2016]

Beller, J. (2016a) 'The Programmable Image of Capital: M-I-C-I'-M' and the World Computer' in *Postmodern Culture* 26 (2), Baltimore: John Hopkins University Press

Beller, J. (2017) 'The Programmable Image', available here: https://www.fotomuseum.ch/en/explore/still-searching/series/30561_the_programmable_image [accessed 05/02/2018]

Beller, J. (2017a) *The Message is Murder: Substrates of Computational Capital*. London: Pluto Press

Beller, J. (2018) 'Derivative Living' keynote at Transmediale 2018. Available here: https://2018.transmediale.de/program/event/derivative-living [accessed 20/04/2018]

Belting, H. (2005) "Image, Medium, Body: A New Approach to Iconnology" in *Critical Inquiry* Vol. 31, No.2 (Winter 2005), pp 302-319

Bennington, G. & Derrida, J. (1993) *Jacques Derrida*. Chicago: University of Chicago Press

Berardi, F. (2009) *The Soul at Work: From Alienation to Autonomy*. Cambridge, MA: Semiotext(e)

Berardi, F. (2015) *And: Phenomenology of the End, Sensibility and Connective Mutation*. Cambridge, MA: Semiotext(e)

Bergson, H. (1988) *Matter and Memory*, trans. N. M. Paul & W. S. Palmer. New York: Zone

Bishop, R. & Cubitt, S. (2013) 'Camera as Object and Process: An Interview with Victor Burgin' in *Theory, Culture & Society* 30 (7/8), pp. 199-219

Blom, I. (2016) *The Autobiography of Video: The Life and Times of a Memory Technology*. Berlin: Sternberg Press

Boyle, W. S. & Smith, G. E. (1970) 'Charge coupled semiconductor devices' in *The Bell System Technical Journal*, vol. 49, no. 4, pp. 587-593.

Brakhage, S. (2003) *By Brakhage – An Anthology*, Criterion DVD.

Cage, J. (1973) *Silence: Lectures and Writings*. London: Marion Boyars

Carpenter, E. (ed) (2016) *The Nuclear Culture Source Book*. London: Black Dog

Casken, S. (2014) 'Damage Mechanisms in Visible Band Cameras Subjected to Continuous Wave Laser Attack' excerpted here: http://www.laserist.org/camera-sensor-damage-thesis.htm [accessed 05/02/2018]

Claerbout, D. (2016) *The Silence of the Lens*. e-flux #73. Available here: http://www.e-flux.com/journal/73/60460/the-silence-of-the-lens/ [accessed 17/10/2016]

Coombes, M. (2013) *Gilbert Simondon and the Philosophy of the Transindividual*. Cambridge, MA: MIT Press

Crary, J. (1990) *Techniques of the Observer*. Cambridge, MA: MIT Press

Crary, J. (2001) *Suspensions of Perception: Attention, Spectacle and Modern Culture*. Cambridge, MA: MIT Press

Crary, J. (2014) *24/7: Late Capitalism and the Ends of Sleep*. London: Verso

Cubitt, S. (2011) 'Current Screens' in Grau, O. (ed.) *Imagery in the 21st Century*. Cambridge, MA: MIT Press, pp. 21-35

Cubitt, S. (2014) *The Practice of Light: A Genealogy of Visual Technologies from Prints to Pixels*. Cambridge, MA: MIT Press

Cubitt, S. (2017) 'The Uncertainty of the Mass Image: Logistics and Behaviours' in *Digital Creativity* Vol. 28 No. 4, pp. 265-278

Cubitt, S., Palmer, D. & Walkling, L. (2015) 'Enumerating Photography from Spot Meter to CCD' in *Theory, Culture & Society* vol. 32, no. 7-8, pp 245-265

Dean, J. (2005) 'Communicative Capitalism: Circulation and the Foreclosure of Politics' in *Cultural Politics*. Vol. 1 Issue 1, pp. 51-74

Derrida, J. (1976) *Of Grammatology*, trans. Gayati Spivak. Baltimore: John Hopkins University Press

Derrida, J. (1995) *Archive Fever: A Freudian Impression*. London: University of Chicago Press

Derrida, J. (2004) *Positions*, trans. Alan Bass. London: Continuum

Derrida, J. (2008) *The Gift of Death and Literature in Secret*, trans. David Wills. Chicago: University of Chicago Press

Dieter, M. (2014) 'The Virtues of Critical Technical Practice' in *differences* 25 (1) pp. 216-230, Durham: Duke University Press

Ernst W. (2013a) 'Media Archaeology as Specific Method'. Available here: https://www.musikundmedien.hu-berlin.de/de/medienwissenschaft/medientheorien/ernst-in-english/pdfs/media-archaeology-as-specific-method.pdf [accessed 20/04/2018]

Ernst, W. (2013) *Digital Memory and the Archive*. Minneapolis: University of Minnesota Press

Ernst, W. (2016) *Chronopoetics: The Temporal being and Operativity of Technological Media*. London: Rowman & Littlefield

Ernst, W. (2016a) *Sonic Time Machines: Explicit Sound, Sirenic Voices and Implicit Sonicity*, Amsterdam: Amsterdam University Press

Ernst, W. (2017) *The Delayed Present: Media Induced Tempor(e)alities & Techno-traumatic Irritations of 'the Contemporary'*. Berlin: Sternberg Press

Farah, M. (2000) *The Cognitive Neuroscience of Vision*. Chichester: John Wiley & Sons

Fetzner, D. & Dornberg, M. (2015) *Insects and Media: An Interview with Jussi Parikka*. Available here: https://jussiparikka.files.wordpress.com/2017/01/insects-and-media-interview.pdf [accessed 10/02/2017]

Fisher, E. (2014) *Gustav Metzger: Lift Off!* Cambridge: Kettle's Yard

Flusser, V. (2000) *Towards a Philosophy of Photography*. London: Reaktion

Fontcuberta, J. (2014) *Pandora's Camera: Photogr@phy After Photography*. London: Mack Books

Fuller, M. (2005) *Media Ecologies: Materialist Energies in Art and Technoculture*. Cambridge, MA: MIT Press

Gaboury, J. (2018) 'The Random-Access Image: Memory and the History of the Computer Screen' in *Grey Room* Vol. 70 (Winter 2018) pp. 24-53

Gabrys, J. (2011) *Digital Rubbish: A Natural History of Electronics*. Ann Arbor: University of Michigan Press

Galison, P. (1997) *Image and Logic: A Material Culture of Microphysics*. Chicago: University of Chicago Press

Guattari, F. (1995) *Chaosmosis: an ethico-aesthetic paradigm*. Bloomington: Indiana University Press

Hangjun, L & Chulki, H. (2008) *Expanded Celluloid, Extended Phonograph*, Seoul: Balloon & Needle

Hansen, M. (2006) *Bodies in Code: Interfaces with Digital Media*. London: Routledge

Hansen, M. (2015) *Feed-Forward: On the Future of Twenty First Century Media*. Chicago: University of Chicago Press

Harwood, G. (2008) 'Pixel' in Fuller, M. (ed) *Software Studies: A Lexicon*, Cambridge, MA: MIT Press

Hayles, N. K. (2012) *How We Think: Digital Media and Contemporary Technogenesis*. Chicago: University of Chicago Press

Hayles, N. K. (2017) *Unthought: The Power of the Cognitive Nonconscious*. Chicago: University of Chicago Press.

Hayles, N. K. (2018) *Cybersemiosis: Meaning-Making in Humans, Nonhumans and Computational Media*. Talk at Winchester School of Art, 03/05/2018

Henderson, L. (2009) 'The Image and Imagination of the Fourth Dimension in Twentieth-Century Art and Culture' in Configurations, Vol. 17 Nos. 1-2, Winter 2009, pp. 131-160

Hertz, G. & Parikka, J. (2012) 'Zombie Media: Circuit Bending Media Archaeology into Art Method' in *Leonardo* 45 (5): pp.424-430, Cambridge, MA: MIT Press

Hertz, G. (2012) 'Interview with Natalie Jeremijenko'. Available here: http://conceptlab.com/criticalmaking/PDFs/CriticalMaking2012Hertz-Conversations-pp11to16-Hertz-JeremijenkoInterview.pdf [accessed 11/02/2017]

Hertz, G. (ed) (2017) *Disobedient Electronics: Protest.* Available here: http://www.disobedientelectronics.com/resources/Hertz-Disobedient-Electronics-Protest-201801081332c.pdf [accessed 25/05/2018]

Howell, S. (2000) *Handbook of CCD Astronomy*. Cambridge: Cambridge University Press

Huhtamo, E. (2004) 'Elements of Screenology: Towards an Archaeology of the Screen' in *ICONICS: International Studies of the Modern Image* Vol.7, pp. 31-82. Tokyo: The Japan Society of Image Arts and Sciences

Huhtamo, E. (2010) 'Thinkering with Media: The Art of Paul de Marinis', in Beirer, I., Himmelsbach, S. & Seiffarth, C. (eds) *Paul De Marinis: Buried in Noise*, Berlin: Kehrer Verlag

Ihde, D. (1979) *Technics and Praxis*. Dordrecht: D. Reidel

Ingold, T. (2013) *Making: Anthropology, Archaeology, Art and Architecture*. London: Routledge

Janesick, J. (2001) *Scientific Charge Coupled Devices*. Bellingham: SPIE Press

Jones, C. (1996) *Machine in the Studio: Constructing the Postwar American Artist*. Chicago: University of Chicago Press

Kahn, D. (2013) *Earth Sound Earth Signal: Energies and Earth Magnitudes in the Arts*. Berkeley: University of California Press

Kane, C. (2014) *Chromatic Algorithms: Synthetic Color, Computer Art, and Aesthetics After Code*. Chicago:University of Chicago Press

Kelly, C. (2009) *Cracked Media: The Sound of Malfunction*. Cambridge: MIT Press.

Kemp, J. (2013) *The Crystal World: Executing a new media materialism*. Doctoral Thesis: University of Westminster

Kera, D. (2012) *Ontological Disobedience in the Age of Tinkering: Crowdsourcing Data or Hacking Hardware?* Available here: http://conceptlab.com/criticalmaking/PDFs/CriticalMaking2012Hertz-Science-pp01to04-Kera-OntologicalDisobedienceInTheAgeOfTinkering.pdf [accessed 11/02/2017]

Kirschenbaum, M. (2008) *Mechanisms: New Media and the Forensic Imagination*, Cambridge: MIT Press

Kittler, F. (1987) 'Gramaphone, Film, Typewriter' *October*, Vol. 41, pp.101-118

Kittler (1999) *Gramaphone, Film, Typewriter*. Stanford: Stanford University Press

Kittler, F. (2006) *Thinking Colours and/or Machines*. Theory, Culture & Society 23 (7), pp. 39-50

Kittler, F. (2010) *Optical Media*. Cambridge: Polity

Knowles, K. (2019, forthcoming) *Film in Transition: Obsolescence, Materiality and Experimental Cinema*. London: Palgrave Macmillan

Kriemann, S & Mertens, H. C. (eds.) (2016) *P(ech) B(lende): Library for Radioactive Afterlife*. Berlin: Spector Books

Kuc, K. & Zylinska, J. (eds.) (2016) *Photomediations: A Reader*. London: Open Humanities Press

Latour, B. (1990) 'Visualisation and Cognition: Drawing Things Together' in Lynch, M. and Woolgar, S. (eds) *Representation in Scientific Practice*. Minneapolis: University of Minnesota Press

Latour, B. (2002) 'Morality and Technology: The End of the Means'. Available here: http://eerikowerhall.com/latour-morality.pdf [accessed: 05/02/2018]

Latour and Woolgar (1979) *Laboratory Life: The Construction of Scientific Facts*. Princetown: Princetown University Press

Law, J. (2004) *After Method: Mess in Social Science Research*. London: Routledge

Lazzarato, M. (2007) *Machines to Crystallise Time: Bergson*. Theory, Culture & Society, 24 (6), pp. 93-122

Lazzarato, M. (2014) *Signs and Machines*. Los Angeles: Semiotext(e)

Lippitt, A. (2005) *Atomic Light (Shadow Optics)*, Minneapolis: University of Minnesota Press

Lippitt, A. (2012) *Ex-Cinema: From a Theory of Experimental Film & Video*. Berkeley: University of California Press

Ludovico, A. (2016) 'The Touching Charm of Print' in Bishop, R., Gansing. K., Parikka, J. & Wilk, E. *Across & Beyond: A transmediale Reader on Post-digital Practices, Concepts and Institutions*. Berlin: Sternberg Press, pp. 100-113

Lukac, R (ed.) (2012) *Perceptual Digital Imaging: Methods and Applications*, Boca Ranton: CRC Press

Lynch, M. (1990) 'The Externalised Retina: Selection and Mathematisation in the Visual Documentation of Objects in the Life Sciences' in Lynch, M. and Woolgar, S. (eds) *Representation in Scientific Practice*. Minneapolis: University of Minnesota Press

MacKenzie, A. (2002) *Transductions: Bodies and Machines at Speed*. London: Contiuum

MacKenzie, A. (2006) *Codecs: Encoding/decoding images and sounds*. Available here: https://www.academia.edu/2718522/Codecs_Encoding_decoding_images_and_sounds [accesssed 17/10/2016]

MacKenzie, A. (2010) 'Every Thing Thinks: Sub-representative differences in digital video codecs'. Available here: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.491.4754&rep=rep1&type=pdf [accessed 22/06/2018]

Marks, L. (2002) *Touch: Sensuous Theory & Multisensory Media*. Minneapolis: University of Minnesota Press

Marks, L. (2010) *Enfoldment and Infinity: An Islamic Genealogy of New Media Art*. Cambridge, MA: MIT Press

Merleau Ponty, M. (2002) *Phenomenology of Perception*, trans. Colin Smith. London: Routledge

Mitchell, W. J. (1992) *The Reconfigured Eye: Visual Truth in the Post-Photographic Era*. Cambridge, MA: MIT Press

Myers, R. (2002) *Display Interfaces: Fundamentals and Standards*. Chichester: John Wiley & Sons

Paglen, T. (2016) *Invisible Images (Your Pictures are Looking at You)*. The New Inquiry. Available here: https://thenewinquiry.com/essays/invisible-images-your-pictures-are-looking-at-you/ [accessed 07/02/2017]

Panofsky, E. (1991) *Perspective as Symbolic Form*. Cambridge, MA: MIT Press

Parikka, J. (2015) *A Geology of Media*. Minneapolis: University of Minnesota Press

Pasquinelli, M. (2008) *Animal Spirits: A Bestiary of the Commons*. Rotterdam: Institute of Network Cultures

Pasquinelli, M. (2015) 'Italian Operaismo and the Information Machine' in *Theory Culture and Society* 32 (3): pp. 49-68

Pasquinelli,M. (2017) 'Arcana Mathematica Imperii: The Evolution of Western Computational Norms' in Hlavajova, M. & Sheikh, S. (eds) *Former West: Art and the Contemporary after 1989*. Cambridge: MIT Press

Pierotti, F. & Ronetti, A. (2018) 'Beyond Human Vision: Towards an Archaeology of Infrared Images'. Available here: https://necsus-ejms.org/beyond-human-vision-towards-an-archaeology-of-infrared-images/ [accessed 08/08/2018]

Rheinberger, H-J. (2012) 'Experiment, Research, Art'. Available here: https://researchcultures.com/issues/1/experiment-research-art.html [accessed 05/02/2018]

Rolls, E. & Deco, G. (2001) *Computational Neuroscience of Vision*. Oxford: Oxford University Press

Sasson, S. (2007) 'We Had No Idea'. Available here: https://web.archive.org/web/20080723231121/http://stevesasson.pluggedin.kodak.com/ [accessed 15/05/2017]

Sampson, T. (2017) *The Assemblage Brain: Sense Making in Neuroculture*. Minneapolis: University of Minnesota Press

Schuppli, S. (2014) 'Entering Evidence' in Forensic Architecture (ed) *Forensis: The Architecture of Public Truth* Berlin: Sternberg Press pp. 279-316

Schuppli, S. (2016) 'Radical Contact Prints' in Kriemann, S & Mertens, H. C. *P(ech) B(lende): Library for Radioactive Afterlife*. Berlin: Spector Books pp 131-161.

Sherman, P. (1981) *Colour Vision in the Nineteenth Century: The Young-Helmholtz-Maxwell Theory* Bristol: Adam Hilger

Siegert, B. (2018) 'Coding as Cultural Technique: On the Emergence of the Digital from Writing AC' in *Grey Room* Vol. 70 (Winter 2018) pp. 6-23

Simondon, G. (1980) *On the Mode of Existence of Technical Objects*, trans. Ninian Mellamphy. Available here: https://monoskop.org/images/2/20/Simondon_Gilbert_On_the_Mode_of_Existence_of_Technical_Objects_Part_I_alt.pdf [accessed 17/10/2016]

Simondon, G. (2017) *On the Mode of Existence of Technical Objects*. Minneapolis: Univocal

Sinha, P. (2012) *Image Acquisition and Preprocessing for Machine Vision Systems*. Bellingham: Spie Press

Smith, R. & Tatarewicz, J. (1985) 'Replacing a Technology: The Large Space Telescope and CCDs' in *Proceedings of the IEEE*, 73 (7): pp.1221-1235

Steigler, B. (2002) "The Discrete Image" in Derrida, J. & Steigler, B. (2002) *Echographies of Television: Filmed Interviews*, trans. Jennifer Bajorek. Cambridge: Polity

Sterne, J. (2003) *The Audible Past: Cultural Origins of Sound Reproduction*. Durham: Duke University Press

Sterne J. (2012) *MP3: The Meaning of a Format*. Durham: Duke University Press

Sterne, J. & Mulvin, D. (2014) *The Low Acuity for Blue: Perceptual Technics and American Color Television*. Journal of Visual Culture, 13. Pp. 118-138

Steyerl, H. (no date) *Politics of Post-Representation*. Available here: http://dismagazine.com/disillusioned-2/62143/hito-steyerl-politics-of-post-representation/ [accessed 17/10/2016]

Steyerl, H. (2013) 'Too Much World: Is the Internet Dead'. Available here: https://www.e-flux.com/journal/49/60004/too-much-world-is-the-internet-dead/ [accessed 22/01/2019]

Treccani, C. (2018) 'How Machines See the World: Understanding Image Annotation'. Available here: https://necsus-ejms.org/how-machines-see-the-world-understanding-image-annotation/ [accessed 08/08/2018]

Väliaho, P. (2014) *Biopolitical Screens: Image, Power, and the Neoliberal Brain*. Cambridge, MA: MIT Press

Virno, P. (2004) *A Grammar of the Multitude: For an Analysis of Contemporary Forms of Life*. Cabridge, MA: MIT Press

Warren, R. & Warren, P. (eds.) (1968) *Helmholtz on Perception: Its Physiology and Development*. New York: John Wiley & Sons

Weizman, E. (2017) *Forensic Architecture: Violence at the Threshold of Detectability*. New York: Zone Books

Woolgar, S. (2005) 'Ontological Disobedience: definitely! {maybe}' in Turner, S. & Sica, A. (eds) *A Disobedient Generation*. Chicago: Chicago University Press, pp. 309-324

Young, T. (1802) *The Bakerian Lecture: On the Theory of Light and Colours*. Available here: http://rstl.royalsocietypublishing.org/content/92/12 [accessed 17/10/2016]

Zylinska, J. (2017) *Nonhuman Photography*. Cambridge, MA: MIT Press