I Image Phenomena of the 21st Century

2 Current Screens

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It is ironic that, as our aesthetics have become more and more materialist, our awareness of screens, which are today the ubiquitous medium of reception, has shrunk to nothing. This is not to say that there are no sociologies of screens: Writers and thinkers from Virilio[1] to McQuire[2] engage in intense discussions of the impact of screens on public and domestic space. Yet there is little attention paid in media and communications to the nature of the screens as material technologies. This chapter addresses screen technologies of the early twenty-first century, from handhelds to billboards. It looks at the material construction of various screen technologies, at the fundamentals of their organization of imaging, and at the bases of the software they use. These issues may be of limited interest in themselves, but, it will be argued, these technological features both express a particular quality of contemporary social life and retransmit it: They are normative technologies. Here lies their importance, for such structures express the nature of public life in particular, and they rearticulate it. Although there is a great deal of innovation in screen design, there remains a curiously static quality to the underlying features. This chapter argues that contemporary and near-future screens have abandoned important potential screen technologies in favor of a particular genus of screens, and that this articulates with a consensus on what we expect from our communications. It concludes that the road not taken can tell us as much about the kind of world we inhabit as the road that we have pursued, and recommends the development of alternative technologies as a key to reconceptualizing the nature and role of public life. The argument is framed by discussions of the environmental limits to growth that must constrain future screen technologies, thus providing a second, ethical layer to the discussion of the mediated life of populations.

Materials

For much of the twentieth century, cathode ray tubes (CRTs) were the fundamental unit of both television and computer displays. The CRT is a glass tube with at one

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end an emitter of negatively charged electrons (the cathode) and at the other a positively charged anode, which attracts the beam of electrons (the cathode ray) to a flattened area covered with phosphorescent materials that light up when struck by the particles. A magnetic coil or electrostatic system focuses the electron beam, and a second magnetic deflector yoke directs the beams' flight toward the desired destination on the screen. In color CRTs, three electron guns fire beams toward phosphors that glow red, green, or blue, separated from one another by a mask. The technology, which derived from both vacuum tubes (perfected in the 1850s) and cathode rays (demonstrated in the 1870s), was first used with the goal of visual display in the Braun tube, the CRT oscilloscope demonstrated by Karl Ferdinand Braun in 1897. CRT oscilloscopes, like CRT radar screens, use phosphors, which tend to keep their glow for some time after being struck by an electron.

The phosphors in television, computer, ATM, and video-game CRTs have a shorter illumination, fading swiftly to allow the next image to differ from the one before. They use innovations pioneered by Vladimir Dzworykin in the Westinghouse and RCA laboratories in the 1920s, where he had fled the Russian Revolution. The central innovation, probably introduced by Dzworykin's mentor Boris Rosing, was the scanning of images prior to transmission. Here the difference from the oscilloscope is critical: Unlike oscilloscope and radar screens, TV and computer CRT displays are formed as grids of phosphors organized in a Cartesian X-Y surface (like graph paper) called a *raster display*. The electron gun responds to incoming signals by modulating its beams as they scan of the whole screen area regularly from left to right and from top to bottom. The level of charge as the beam strikes a given square on the grid determines the "luma" or brightness signal, with a correspondingly brighter reaction from the phosphor targeted at that specific address on the screen. Oscilloscope and radar screens, in which the intensity of the charge is kept constant, steer the electron beam directly on the X and Y axes using magnetic plates seated inside the electron gun. This allows arbitrary movement in response to incoming signals from various electronic instruments like microphones and radar telescopes. This was the type of screen used in Ivan Sutherland's Sketchpad, an invention to which we will return. This first application of the CRT has been abandoned in television and subsequently (and perhaps consequently) in computer technologies, where signals such as component or composite video and RGB are organized to match the raster grid.

The materials involved in CRTs are expensive and many of them toxic and potentially dangerous to dispose of. Color CRTs require up to 32,000 volts in the screen anode (though monochrome sets use much lower voltages): The energy requirements of such devices are intense. Since the voltage/brightness connection means that unilluminated phosphors require no charge, bright images such as the typical white of a computer word-processing package require higher degrees of energy than darker images (the avowed reason for Google's *Blackle* experiment, which reproduces Google's search pages reversed out to reduce power usage: see <http://www.blackle.com>). The glass tube is under extreme pressure—implosion as a result of the vacuum can send fragments ricocheting at lethal speeds—requiring very strong glass in substantial quantities, and often metal reinforcing bands, also under extreme tension. Recycling these components can be a risky process. The glass itself is leaded to minimize the radiation risks associated with both the high energies of the cathode ray, which generates X-rays on impact with the screen, and ions generated as a by-product of running the electron beam. This lead in the glass, the often toxic phosphors which line the screen, and the frequent use of barium in the electron gun assembly all add to the toxicity of the recycling process. Legislation in the United States and the EU prevents throwing CRTs into landfill, but cannot legislate for the recycling villages of Southern China[3] and West Africa, where most Northern hemisphere electronic equipment ends up. The Basel Action Network[4] estimated that in 2005 approximately 400,000 junk computers were arriving in Lagos alone.

Liquid crystal displays (LCDs) pose similar problems, although their power usage is much lower than CRTs, which they have largely displaced in the computer market. Overtaking CRT sales in 2004, LCDs were projected to sell 50 million units worldwide in 2008, and to double in total by 2011. Found in digital watches, mobile phones, laptops, and increasingly in flat-screen TV and monitor screens, waste LCDs constitute one of the fastest growing recycling problems of recent years, with increases in end-of-life statistics projected at 16 to 25 percent every five years. The LCD backlights are the most serious pollution hazard, as they contain significant quantities of mercury. The perfluorocompounds used in the crystals themselves have a far higher greenhouse effect than carbon dioxide: up to 22,000 times higher on the global warming potential (GWP) index.[5] While the mercury can be recovered in demanufacturing processes (so long as manufacturers, mainly based in China, Korea, and Japan, abide by regulations established in key markets like the EU), the crystals are typically incinerated. The manufacturers association has established high-heat incinerators, backed up with alkaline scrubbers to react with remaining perfluorocompounds, but these too use very significant amounts of energy (though Sharp established a "green-powered" recycling plant in 2008). Many appliances are dumped when the screens have relatively minor failures: Recyclers can frequently repair and reuse them. But many will find their way into the recycling industry, where the mercury and cadmium from the integral batteries, the indium-tin oxides used in electrodes, and the unpredictable breakdown products of the organic compounds used through the assembly, from polarization and orientation layers to screen coatings, all contribute to the hazards. The problem is exacerbated by the economics of waste recovery, which suggest that the most cost-effective method is manual disassembly.[6] Despite disputes over the toxicity of the components on LCDs, there is general agreement that they are poorly biodegradable, and are potentially significant water contaminants.

The ubiquity of LCDs in mobiles places them alongside other dangerous rare earths like selenium and germanium, pointing to a further material problem: the limit to the availability of these materials, essential to the production of chips and batteries. The levels of penetration of personal devices in the West is not sustainable across the rapidly developing markets of India and China, let alone the remaining portion of global population living in the underdeveloped world. The screens in mp3 players and digital cameras, and the other components associated with them, pose not only recycling and recovery problems but suggest that without radical change in their design, there will not be enough raw material to reproduce the West's expectation of multiple, individually owned and used devices for each member of the population. The strategic importance of rare earths has sparked fears that China, which produces 95 percent of the world's lanthanides, may be introducing export controls, placing its electronics industries in a powerful position to dominate twenty-first-century manufacturing, either through domestic firms, or by forcing transnationals to move their manufacturing to China in order to access the necessary raw materials. Though global reserves include 42 percent outside China's borders, refining capacity is limited, extraction costs are often higher, and in some instances, as with Arafura, an Australian rare earths mining company, China has moved to purchase significant shares.[7] The possibility of trade wars on a level with those currently being fought over access to oil may loom for the high-tech industries, and indeed for green technologies: Hybrid cars require up to two kilograms of rare earths for their batteries alone.

Architecture

It is clear that our "immaterial" culture is highly material, especially when we consider its ecological footprint in raw materials, in use and at end-of-life. Without delving into the manufacturing process, which would require another chapter, suffice it to point out that Dell Computers, a large but otherwise typical U.S. computer brand, uses up to 98 OEM/ODM (original equipment manufacturer/original design manufacturer) sources to produce their equipment, the vast majority in developing countries or in export-friendly free-trade zones like the notorious *maquiladoras* of the Tijuana U.S.–Mexico border country, where pay and conditions are far below developed nation standards. Screens are a typical OEM/ODM item, installed without the manufacturers' name attached, and only sometimes branded by an on-seller. For example, the disc drive in my MacBook Pro is credited to Matsushita, who almost certainly has outsourced its manufacturing offshore, while the memory manufacturer is listed as "0x127F000000000000," and the LCD has no vendor or manufacturer named in any form. As is typical of information capitalism, key brands like Apple, Matsushita, and Sony (who provide my batteries) do not manufacture components themselves, and frequently do not even own the assembly plants where the final products come together. Instead they concentrate on the core business of intellectual property: trademarking the brand, patenting hardware, and copyrighting interlinked software and content. Although corporate research and development is now also often outsourced, for example to India in the software industry, or to increasingly corporatized universities in the materials science field, core trade secrets and the development of core innovations will typically be the one area of corporate concern to be kept as close as possible to the center of operations.

This situation suggests the following important question: Is it the case that, because of the proximity of hardware innovation to corporate headquarters, there is a structural homology between the design of major components of digital devices such as screens and the corporate culture in which they are formulated? The question is not entirely naive. Isabelle Stenghers[8] points out that the history of science and technology studies has presented two competing paradigms, that of the autonomy of science and technology and that of symptomatic technology and science. In recent decades, however, the work of investigators including Stenghers and Bruno Latour[9] has increasingly suggested that the assemblage of agencies involved in scientific and technological innovation are neither rational—a presumption of the autonomist thesis—nor necessarily efficient—a correlative of the symptomatic thesis. The emerging new digital architectures, for example those of the LCD, LED (light-emitting diode), and DLP (digital light processing) screen technologies, are of necessity built on existing standards. They must, for example, be able to at least speak to component and composite video, recognize different color spaces like RGB and YPbPr, and connect to existing infrastructures such as the electricity grid, broadcast transmission wavebands, and the Internet. These accumulated elements of the environment into which new technologies emerge is also a regulated environment, and as several commentators have suggested, at both national and global levels, media regulation rarely gives evidence of a unifying policy goal. Rather, governance accumulates in layers, with regulations for each technology framed inside the policy objectives of the epoch in which it emerged: freedom of speech for the U.S. press, for example, but universality of access for telephony.[10] The regulatory environment "reflects the fact that law-makers simply wrote a new law for each new network as it arrived."[11] It is therefore perhaps understandable that, given the principle that the more deregulated a market is (and this is surely the case for the global market in electronics), the more regulations are required to govern it,[12] electronic screen design is formulated not only on the technological affordances of the day, but on the accumulated technical practices of the past, and the regulatory framework of the present, which itself is typically a historical aggregation. We can observe this in the economics of recycling: Manual labor (and therefore, the labor of developing nations) is the most efficient way to get rid of WEEE *because*, prior to regulation, there was no incentive for manufacturers to make automated demanufacturing a possibility. Even today, regional (NAFTA, EU) and international (the Basel Framework) agreements notwithstanding, the global trade in e-waste is to all intents and purposes an export trade in toxins. This trade is the more insidious to the extent that the electronics industry depends on innovation for success. Even the biggest market, such as that for personal mobile phones, flattens out once it reaches saturation. At such junctures, the industry must innovate or die. Thus we enter a cycle of built-in obsolescence equivalent to that of the Detroit motor industry in the 1950s and 1960s. The necessary by-product of such speedy electronic obsolescence is e-waste.

This is not to say that innovation is never virtuous. The LCD is a far less power-hungry technology than equivalent CRTs, for example. It is to say, however, that innovation is never undertaken without a cost, nor is it undertaken in an environment of absolute creative freedom. As an example, let us return to the raster grid, incorporated as a core technique in the innovation of the CRT. The raster grid has its own genealogy, specifically in the development of wire photography, initially demonstrated by Edward A. Hummel and Arthur Korn in 1900 and 1907 respectively, and industrialized by Bell Labs and Associated Press in 1935. This technology, which used a rotary scanning technology related to the earliest experiments in television, produced a halftone grid of dots that assembled into a still image, transmitted over telegraph wires. The halftone process itself had been pioneered by one of the key figures in the invention of photography, William Fox Talbot, in the 1850s and in industrial use by the 1870s. Half-tone printing uses a similar grid of dots and remains the core technology of photolithography, the printing technology common to both book production and chip manufacture. The halftone's unique characteristic is that it lays its grid at a 45 degree angle to the horizontal, on the basis that the human eye sees parallel lines less acutely when they are not aligned with the horizon. With that exception, it may trace its own ancestry as far back as the Renaissance, to the engraving of lozenges for shading in intaglio printing. The significant properties of the raster grid are, then, threefold: It is aligned on the horizontal axis; it is automated; and it is attached to a clock function in which the whole screen is scanned in numerical order and refreshed at regular intervals (typically 120Hz in NTSC and 200Hz in PAL and SECAM). It is in this sense a Cartesian coordinate space, each pixel enumerated along the X and Y axes, and distinguished over set increments of duration. It is a thoroughly mathematical space, and one that has been strongly identified with both modernity and the broad cultural project of modernism.[13]

Thus, we should not be surprised that the technical innovations of the LCD rest on a far older substrate of the grid, not least since computers are now almost universally calibrated to produce video signals designed to play out on raster screens. CRTs, however, are rather less rigid than LCDs. The scattering of phosphors on the luminescent surface is itself more random, and the illumination of one phosphor tends to blur into the light from its neighbors, so that even if the electron gun tracks over the screen in linear order, the phosphors themselves are less rigidly contained. Sony's Trinitron aperture grille system for color reproduction in CRTs was designed to limit this fuzziness, by laying a grid of vertically aligned thin black wires over the screen in order to minimize the interference between phosphors, and so increase apparent resolution. This step preceded and pointed the way toward the increasingly rigid mathematicization of the raster array, much as Fox Talbot's textile screen preceded the lined glass sheets of the industrial halftone process.

LCDs do not rely on electroluminescent phosphors for their illumination but on mercury-vapor fluorescent backlights. Requiring much less power than the high voltages associated with CRTs, they both produce far less unwanted radiation than the older technology, and are eminently suited to battery-powered personal devices like laptops and handhelds. LCDs sandwich their crystals between two layers of polarized glass, arranged so that if no voltage is applied, light cannot travel through one layer and through the next. The liquid crystals (so called because although they are liquid they retain some structural characteristics of crystals) carry light between the polarized plates and change their orientation according to whether they receive a voltage from transparent indium-tin oxide electrodes placed over the glass sheets. When charged, they untwist their "relaxed" helical shape, and the light is blocked, creating black pixels; uncharged, they let the light pass through. Small displays have a discrete pair of electrodes for each pixel. Larger displays reinforce the grid structure by supplying electrodes in rows on one side of the screen and columns in the other, so that each pixel has a unique row-column address, without requiring an independent power source. The surface on the visible side of the screen is covered in a layer of red, green, and blue color filters, one of each to each pixel, allowing millions of color combinations. There is a general feeling, however, that LCD color is less subtly graded, has a narrower gamut, and in inexpensive models is less bright than CRT screens.

The same raster grid structure is apparent in other screen technologies, such as the plasma displays competing for dominance in the domestic high-definition television market. Here noble gases (neon, argon, and xenon) contained in phosphor-coated cells are ionized and heated to a plasma by voltage difference, controlled as in large LCDs by long electrodes, in this instance in rows along the back plate and columns inside the front. The ultraviolet photons given off by the plasma then trigger the phosphors to illuminate as subpixels of red, green, and blue, as in LCD technology. Indeed, this release of photons from agitated phosphors is the basis for shadow-mask CRTs, in which a triad of red, green, and blue-emitting phosphors was first established as the basis for electronic color screens. Plasma screens use power comparably to CRTs, but the size of screen, the relative brightness, and the viewing angle are all greater than that of LCDs.

Similarly, the digital micromirror device (DMD), the chip at the heart of digital light processing projectors and rear-projection TVs, sets up an array of tiny mirrors,

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each corresponding to a pixel, brightly illuminated and controlled to shift very swiftly on their axes. One orientation is "on," another is "off," and rapid oscillation between the two provides grayscale by reflecting some of the light away from the screen. In single-chip DLP projectors, color wheels spinning up to ten times per frame deliver the color component of the image; three-chip projectors for high-end use a prism to split the illuminating white light, passing one of the red, green, or blue wavebands to one of the three chips, which then reflect that color component onto the screen. This too has its roots in an older color technology, the three-color Technicolor camera of 1932. Though they began with mercury-vapor arc lamps (with the same color signature as LCDs), since 2006 patented LED (light-emitting diode) technology has increasingly been applied to DLP projection, with longer life, lower power consumption and comparable illumination, at least for domestic uses. At the opposite end of the market, Texas Instruments, who devised DLP and DMD, announced in 2009 its intention to develop the technology for use in handheld devices. But again, like other emerging competitor technologies in the high-definition and projection markets such as LCoS, DLP once more reproduces the raster grid, even if it has managed to exceed competitor technologies' color gamuts, an issue to which we return in the next section. The Cartesian grid is hardwired into the architecture of the DMD chips used DLP, as it is into the screen displays of plasma and LCD. The question then becomes, does this architecture also shape the use of these devices? Is the mathematicizing instrument of the Cartesian grid, which dominates the architecture of dedicated visualization chips and screens, also the overwhelming structure of twenty-first-century visuality? If the answer is yes, then the following question must be: Does it matter? Does it matter whether our images come to us in the random spatter of silver halide molecules or the ordered arrays of the raster display? Does it tell us anything about who we are, how we live, and perhaps most of all how and what we communicate?

Protocol

In the influential book *Code and Other Laws of Cyberspace*, Lawrence Lessig[14] gave the phenomenon a catchphrase: Code is Law. He was writing specifically about the use of digital rights management (DRM) code, which at the time was threatened as a new way of preventing copyright infringements. As we have seen, copyright and other intellectual property laws are of vital significance to contemporary corporations. Lessig does not suggest that it should be otherwise, although he offers nuanced arguments concerning the degree and duration of protection that can be considered just. But he does have a lawyer's disagreement with the principle that copyright owners have the right to make it impossible to infringe on their property rights. DRM effectively does this: It undertakes to make it impossible to commit the offense of infringing copyright.

Alex Galloway[15] coined the term "protocol" to express a more widespread phenomenon. Software comes in various forms: as operating system (Windows, Linux), as applications (Adobe, Autodesk), and as protocols. Protocols are common on the Internet: SMTP is standard mail transfer protocol; HTTP indicates pages using the hypertext transfer protocol; and below such familiar protocols lie more pervasive ones, specifically the TCP/IP suite (transmission control protocol/Internet protocol), which provides layers of nested protocols (applications, transport, Internet, and link), which together allow the entire system of computers communicating with each other to perform. Drawing on Deleuze and Foucault, Galloway sees protocol as the next period in a historical process, first described by Foucault, which has seen power migrate from sovereignty (the king's right to decide the life or death of a subject) to discipline (the inculcation of rules of behavior in the individual subjects of a state), and from thence to governmentality and biopolitics (the management of populations according to statistical norms). Deleuze added a fourth period: the "societies of control," where the codes operating in society effectively determine what can and cannot be done in it—much as the highway code determines how one may or may not drive a car. Technically we are free to drive—or to behave in electronic environments—just as we please, and to take the consequences if we do something illegal. But in the emergent societies of control, and more particularly in the era of protocol as the governing feature of the Internet and so of a vast swathe of contemporary life from correspondence to global finance, we are not free to disobey. The very same protocols that allow us to disport ourselves in cyberspace also constrain us to act according to the rule-set that underpins it.

It is in this vein that we turn our attention to the parallel infrastructure of software that underlies the electronic image. We have already noted in passing one or two such infrastructural themes. One of these is the question of color gamuts, the range of colors that a given screen is able to reproduce. The visible spectrum spans the waveband between, roughly, 400 and 800 nanometers. On average, a human eye has 120 million rods and 7 million color-sensitive cones, the latter concentrated in the fovea, at the center of the field of vision where they reach densities of 60,000 per square millimeter; the equivalent numbers for digital cameras are about 20,000, and for color photographs about 30,000.[16] At their best, digital screens can reproduce only about 50 percent of the visible spectrum. To make the most of a bad business, the outlying colors are moved inward toward the reproducible sector—the gamut of the screen. But that process does not account for the acute perceptual facility we have, especially within that foveal arc of one or two degrees where we focus our attention, for distinguishing between colors. It is then not the absolute hue or saturation that is at stake but the differences between them. Screens are calibrated (as are the signals they coordinate) so that the color gamut squeezes the full spectrum into the available gamut *while preserving the relationships of difference between colors*. This would be more

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acceptable, perhaps, if all screens used the same algorithms to redeploy colors, and if all computers shared a single color space. Unfortunately, they do not. The manufacturers of LED versions of DLP boast a much wider gamut than is available on LCD, which in turn is widely regarded as having a poorer gamut than modern CRTs. Likewise, different chips used to gather images have different gamuts: CMOS chips, previously considered only good enough for low-resolution applications like mobile phone cameras, have found a significant place in scientific imaging, partly because of their greater gamut than their competitor CCD chips.

The fact remains that digital outputs (including both screens and printers) have a much reduced color gamut compared either to normal human vision or to older color technologies like oil paint. Worse still, in network conditions, where it is impossible to know in advance which kinds of display will be used to view some piece of content, there is no way to prepare the file for optimum viewing by the far-end user. This may be critical when the files in question are being prepared for analog media such as cinema film or color printing, and is also significant for such uses as the color branding of companies or the standardization of flags and other important insignia. Here the standard recourse is to entirely nondigital media, such as the color "chips" purchasable from the Munsell Corporation, or the printer's standard recourse, the Pantone color system, both of which use printed materials for comparisons, and a numerical reference that can be passed in a more reliable, nonvisual form, to network collaborators. The mathematicization of color, which began with Newton in the seventeenth century, resulted in its commodification at the end of the twentieth.

Can anything similar be said of the other elements composing the protocological layer of screen technology? Perhaps the most important of these are the codecs, compression-decompression algorithms used to compress signals for transport, and to "unpack" them on arrival. The codecs sit a layer below such standards as PAL and NTSC, and have historically developed in relation to emergent uses such as Internet, satellite, and high definition. They have also historically been involved, because of their importance to emerging hardware and architectures, in heavily regulated environments where design can be as much influenced by national interests (for example, in protecting domestic equipment manufacture) as by elegance or efficiency. Many codecs are in use, generally standardized through the International Organization for Standardization (ISO), and some of them are wholly proprietary. The major ones, however, are MPEG-2 and MPEG-4, both used as standard codecs for broadcast television, though MPEG-4 has much broader additional capacities, for example for high-definition applications like Blu-Ray, and for encoding and decoding bitstreams representing 3D objects and surface textures. The MPEG-4 codec was devised, like the other MPEG formats, by the Motion Picture Expert Group, now a subcommittee of the Internet Engineering Task Force, but elements of the codec are owned by 640 institutions (including the military, a feature that goes back to the 1916–1918 period when the U.S. Navy took control of all radio patents[17]) and corporations. The complexity of its organization is compounded by its composition in "Parts," sometimes referred to as "layers," many of which are optional for people implementing them in specific circumstances. Thus, few nonprofessional users will require VRML support for 3D rendering, while others will find a use for Part 13, which provides for encoding DRM in MPEG-4 signals. But what is important is not such features, nor the ownership of patents, nor even the protracted negotiations required before licenses could be agreed between the patent owners, but the fact that, as Adrian Mackenzie has it, "Codecs affect at a deep level contemporary sensations of movement, color, light and time."[18]

The MPEG codecs, which lie at the deep level of such familiar tools as Windows Media, VLC, and commercial DVDs, use "lossy" compression, a term that refers to the way the decompressed signals lose resolution and color information compared to the original uncompressed signal. Although some rare codecs do promise lossless transmission, the continuing problem of bandwidth economics continues to foster lossy standards. For terrestrial and satellite broadcast transmission, digital signals are far more efficient than analog, but competition for wavebands with cell phone and other uses makes bandwidth a valuable commodity. Even in wired environments, speed of transmission is regarded as more valuable than the quality of the received image, while the carrying capacity of laser-read discs like DVD and Blu-Ray also requires considerable compression to fit feature films plus associated extras on a single side. Of the various tools used, perhaps the most significant is vector prediction.

Common to the various MPEG codecs, and especially visible in the H 261 codec that underlies the YouTube proprietary .flv format,[19] vector prediction works by assembling pixels into blocks, macroblocks, units of 4×4 or 16×16 pixels that can be treated as average hue, saturation, and brightness values. On the presumption that, for example, green grass and blue sky areas will remain the same from frame to frame, the codec "guesses" that the next frame will be by and large similar to the current one. To aid this process, the codec interpolates key frames, in the manner developed by animators around 1915, each of which establishes the beginning and end of an action, allowing the codec to interpolate the most likely sequence of changes that will take the image from the first key frame to the last. This economically satisfying system leads to advice to users to minimize movement in the frame, which tends to demand more frequent key frames and therefore more bandwidth. The result is the self-fulfilled prophecy of YouTube populated by talking heads and minimally animated flash video, or, alternatively, slow downloads (with attendant loss of interest among downloaders) for those videos that ignore the advice.

Such technologies allow a signal to be decoded that is legible. They are good-enough technologies, confining expectations to the likely loss of resolution and color depth. The vector-prediction algorithms are based on the typical broadcast, and function both normatively, by accommodating genres, like sport, that have the greatest uptake among users, and descriptively, deploying the averaging techniques first developed by Alphonse Quetelet in the nineteenth century to establish the concept of the "average man."

Conclusions

As Mackenzie[20] notes, the way a codec "pulls apart and reorganizes moving images goes further than simply transporting images. . . . Like so much software it institutes a relational ordering that articulates realities together that previously lay further apart." Quetelet's "social physics" was an ultimately successful attempt to apply the mathematicizing principles of physical sciences to the emerging idea of the social sciences. Statistical norms provided in the first instance data on the average height and weight of citizens, but then increasingly on their average opinions, habits, and behaviors. It was the sociological expression of the idea of the market that had developed out of eighteenth-century radicalism in the hands of Immanuel Kant, Adam Smith, and Jeremy Bentham, and which in Foucault's analysis would form the fundamental liberal and later neoliberal formation of biopolitics: the management of populations.[21] If on the one hand, as we have seen in the case of color gamuts, the kind of mathematicization espoused by Quetelet and later opinion pollsters tended toward commodification (of audiences as sold to advertisers, for example), on the other it had a direct impact on the concept of liberal government.

The invisible hand of the market first identified by Adam Smith is at heart the aggregate rationality of individual acts of exchange influenced by such irrational factors as advertising and brand loyalty. Though every individual act can be construed as undertaken in a free environment, averaged across the whole of a market, they become statistical probabilities, much as the likelihood of death from drunk driving or smoking-related illnesses can be calculated from actuarial records. The contention implicit in the foregoing analysis is that the raster grid of dominant screen displays is indistinguishable from the Cartesian space deployed by Quetelet and every subsequent statistical sociologist to analyze the existence of *l'homme moyen*, the average person, in the environment not only of historically accumulated technological practices, nor of the historical layering of architectures and protocols, but of a regime of commodification and power whose fundamental premise is the exchangeability of any one good for another, any one person for any other, and all possible behaviors as norms or departures form the norm: a regime of accountancy rather than accountability. At the microlevel, our technologies, this chapter has argued, take the shape of the biopolitical and information-economic structures that shape our society at the macrolevel. To call this regime a database economy is perhaps to succumb to the same demand for efficiency that characterizes government in our epoch, yet it is also a way of throwing into question what has become of the publics of such technologies, as they traverse cityscapes on the one hand decorated with huge urban screens, and on the other characterized by individuals bent into the increasingly screen-dominated intimacies of handheld devices. In materials, architectures, and protocols, we can observe the structuration of contemporary media not only by their histories and by the immediate and conscious influence of regulatory environments, but by the very shape of the social organizations in which they emerge. Contemporary innovation, while it seems to churn far faster, is only the more deeply hamstrung by the rapidly accumulating mulch of previous inventions and previous regulatory interventions.

In our haste to populate our lives, intimate and public, with screens, we have opted for the good enough over the best possible, and in the process abandoned technical trajectories that might have suggested other social and political capacities and affordances. The biopolitical management of populations that Foucault describes is entirely congruent with, and in some ways reflective of the liberal conception of the market: In both systems, innumerable interactions and exchanges are aggregated in the mass and there mathematically rendered. The Cartesian grid is the tool of choice for statistical graphing, not least because once a line has been drawn of number against time, it can be extended into the future. This is the central tool of planning, of the management of markets and populations that constitute the database economy. It not only shares the grid formation, but is the managerial expression of the kinds of vector prediction analyzed above in the H.261 codec. Prediction, foreknowledge based on statistical aggregation, the enumeration of the enumerable: These have become the ingrained characteristics of the contemporary screen in all its manifestations.

All, that is, bar one: the oscilloscope screen technology utilized in early experiments in computer graphics by Ivan Sutherland, mentioned briefly in the opening pages of this chapter. Sutherland's vector screen, free from the obligation to scan the raster grid in clock time, remains an available technology still deployed in air-traffic control and scientific instrumentation. Its capacities have been ignored in the development of the Cartesian raster display. Yet the vector display is the natural way to display the vector graphics that increasingly constitute the central platform of object-oriented visualization. The loss of vector screens in the age of vector graphics, and their replacement with codecs whose central innovation comprises new tools for making vectors visible on raster displays, suggests both a concrete avenue for twenty-first-century technical innovation, and the kind of lacuna in innovation that may only be typical in situations where there is a diagrammatic or structural interchange, a homological assemblage, operating between key technologies like contemporary screens, and core values and processes of both economic and political life. The oscilloscope allows for the arbitrary. Unlike our common screens, which have become attuned to the normative workings of the database economy, the vector screen is an expression of a freedom we

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have sensed, that we have imagined as potential, and which still lies unrealized in the storeroom of residual media. If technologies are articulations of social formations, then genuine innovation, or turning back to follow the road not taken, may well introduce us to a new way of imagining and realizing alternative social formations. Perhaps this cannot be achieved with respect for the poor and for the ecosphere, but we know for a certainty that the road we did take has not benefited either of them. It is time to set the vector free.

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