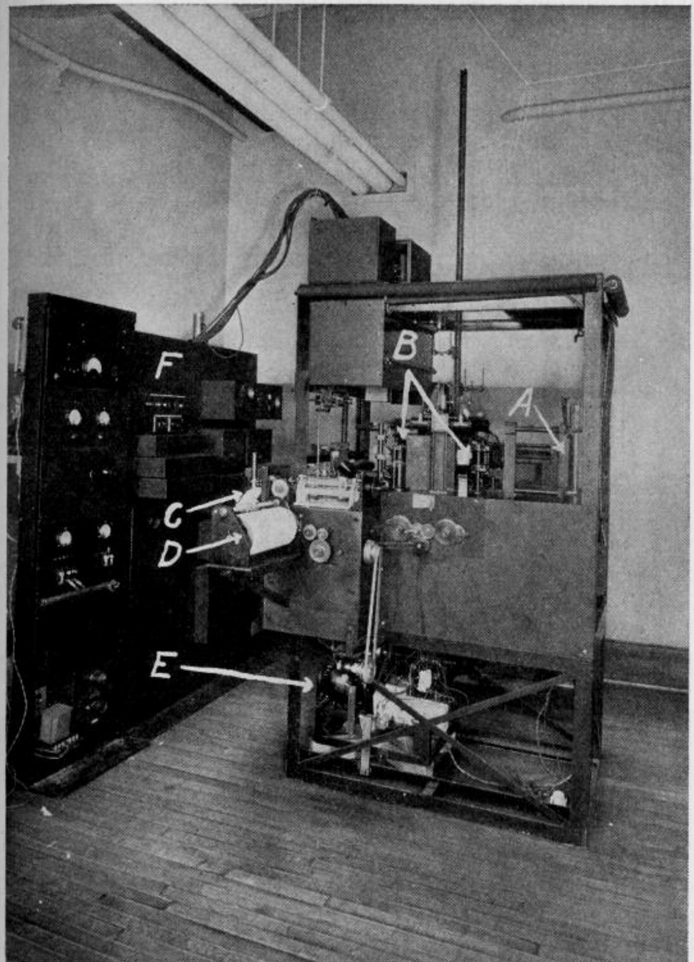


Photograph of Cinema Integraph showing principal mechanisms. *A*. Line source of light. *B*. Driving sprockets. *C*. Recording counter. *D*. Recording drum. *E*. Servo-mechanism. *F*. Relay control panel.

The Cinema Integraph analog computer for harmonic analysis. From *The Journal of the Franklin Institute* (1940).

 doi:10.1162/GREY_a_00149

The Coupling of Cinematics and Kinematics

KYLE STINE

The term *cinema* traces back to the 1830s when André-Marie Ampère adopted *cinématique*, from the Greek κίνημα, movement, to describe "the purely geometrical science of motion in the abstract."[1] Citing Ampère, German engineer Franz Reuleaux reverted to the hard *k* of the Greek in his *Theoretische Kinematik* (1875) to name the new discipline of machine kinematics. Through this German detour, the term entered the English language as the science of machine design. English speakers thus inherit two concepts from the same source: kinematics, passing through a mechanical lineage of iron and steel; and cinematics, comprising the synthesis of movement in virtual space.[2]

Far from an accident of terminology, this divergence maps a coupling at the basis of all cinematic creation and all machine manufacturing, a coupling of optics and mechanics. From automotive assembly to computer animation, from surveillance systems to machine vision technologies, processes of picturing and machine movement fold into one another, enhancing capabilities on both sides. The history and theory of this coupling remains largely unexplored. Research on the role of tool use in human intelligence charts a coupling of hand and eye, which anthropologist André Leroi-Gourhan (1964) expands to include the array of the senses: "*Tools for the hand, language for the face, are twin poles of the same apparatus*."[3] The hand-eye system, as the last half-century of research in robotics and artificial life attests, is not singular to biological organisms. Its history in the machine arts and in the arts of sound and image reproduction—while often enlisting human beings to be the eyes to technical hands and to act as the hands to technical eyes—includes an extensive list of iterations. Among these are the interrelations between optics and precision mechanics, which from the seventeenth century fueled innovations in fine tools and telescope lenses; the folding of picturing and calculation, extending historically from the *calx* (literally, pebbles) of ancient counting boards, which stood in for numbers that fingers alone could not represent, to the height of digital cameras today; and the coupling of cinematics and kinematics.

Theorists such as Lev Manovich have offered a vision of *convergence* wherein various media technologies, previously subject to "separate historical trajectories," are increasingly subsumed by digital computing.[4] In this article, I propose instead that the atavistic coupling of computing and cinematics indicates ways in which these technologies might better be seen as dynamically related to one another. Rather than a convergence of the computer and cinema, what calls for attention is the folding of picturing and calculation—the two sides of which increasingly appear as dual aspects of a single phenomenon. This folding is a dynamic that runs all the way down to the very groundwork of computers and digital cameras today, to optics and photography (as "writing with light") and the methods of microphotography, developed at Eastman Kodak, which became photolithography used to print the masks for transistors and integrated circuits. The issue is not that the computer overtakes cinema with the advent of digital imaging; instead, cinema is there from the beginning as the eyes to its digits. Reckoning with the Cinema Integraph, an early analog computer, offers a crucial way to address the film-theoretical problem of digital cinema through cybernetics.

The Cinema Integraph

In 1955, Norbert Wiener delivered a talk to the New York Club of the MIT Alumni Association on the question of automation, or as the founding cyberneticist would say, "automatization": "I will not say 'automation' for anybody. [Laughter]." Wiener's lecture traced the development of automation back to the 1930s and to his and Vannevar Bush's work on analog computers. In an introduction to the talk, Gordon S. Brown, Wiener's colleague at MIT and acting head of the Department of Electrical Engineering, provided a window into Wiener's process of discovery:

> Dr. Wiener frequently gets his profound ideas when he is bored at a theater, and on one such occasion it occurred to him that some form of radiation could be used with an appropriate assembly of masks, sources, and receptors to evaluate the integral of the product of two functions with a variable parameter under the integral sign—in simple words, the evaluation of a parametric product integral. The development of this idea fueled the evolution of a number of computing machines, one of which was the Cinema Integraph; others were Dr. Bush's Differential Analyzers. My introduction to servomechanisms stemmed from my association with them.[5]

Wiener confirmed the story. "It was the old Copley Theater in Boston," he remembered.[6] In the early 1930s, the Copley Theater was a venue for stage performances, but Wiener was also an avid moviegoer, using his leisure time to take walks, as he mentions in his autobiography, "with an overdose of films and theater in between."[7] His experiences at the movies may well have been formative. During the intermission that night at the Copley he conceived of an optical idea of computing that would lead to the first analog computer at MIT to venture beyond the mechanical designs of Bush's machines by using motion picture film. In his autobiography, Wiener relates how profoundly the idea took hold of him:

> [A]n idea came into my mind which simply distracted all my attention from the performance. It was the notion of an optical computing machine for harmonic analysis. I had already learned not to disregard these stray ideas, no matter when they came to my attention, and I promptly left the theater to work out some of the details of my new plan.[8]

Wiener was not an engineer, so the work on the project fell to Bush who, as Wiener mentions in his talk, lent him Brown, then a young engineering student recently arrived from Australia. The Cinema Integraph was designed to solve an integral that occurred frequently in electrical network problems and in this way connected to Brown's work with Harold Hazen on the Network Analyzer.[9] More immediately, it was an extension of the work started by Truman Gray on the Photoelectric Integraph, a machine using cardboard masks to perform similar functions of harmonic analysis.[10] Later in his life, Brown reflected on his decision to take on the Cinema Integraph as a doctoral thesis: "The notion of integrating spheres had become more clearly understood and I had become intrigued by them. Photocells were improved vastly over what photocells Truman Gray had. And then the idea of making a fully-automatic, self-recording machine looked like a real challenge."[11] Beyond the new photocells, the crucial advance over Gray's machine was the use of motion picture film, which allowed for much greater speed and accuracy. The masks printed on film were also more durable, which was important because they often served as "kernel functions" common to many different problems and thus could be reused.

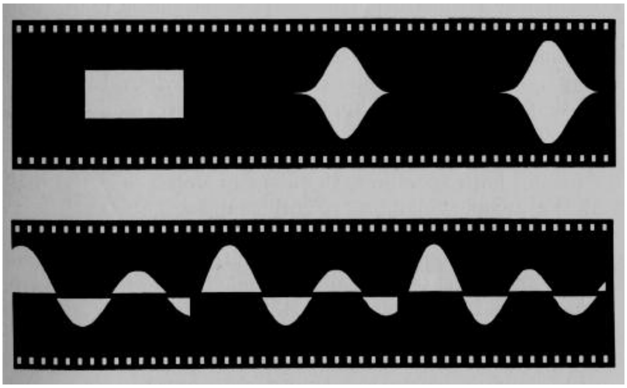
The engineering path of the Cinema Integraph in this way followed a line of development similar to that which cinema had cut four decades earlier when paper film had served as a suitable early medium before the widespread adoption of Eastman celluloid film.[12] Returning to the origins of celluloid in another way, the machine used 70 mm Kodak film (the use of 35 mm being the result of an early cost-cutting measure by W.K.L. Dickson at Edison Laboratories).[13] As with the contemporaneous development of film sound, the Cinema Integraph performed calculations by moving film past a bright incandescent light, creating variations in light patterns in a manner nearly identical to the optical soundtrack. Like the optical soundtrack, the photoelectric receiver transduced variations in light patterns into variations in electrical current. Where it differed was in its output. Variations on an optical soundtrack became sound. In the Cinema

Integraph, a writing device connected to the photoelectric receiver recorded the solution either as a curve or as a table of numbers. Brown's description of the machine left little doubt why it was called *cinematic*. "The multiplication process is *visualized*," he wrote. "The integration process is *visualized*."[14]

The function patterns printed for the Cinema Integraph shared the same basic principles as several contemporaneous synthetic sound experiments by Oskar Fischinger and Rudolf Pfenninger.[15] They are, in fact, nearly indistinguishable from Norman McLaren's later animated sound strips, both consisting of regular waveforms of the variable area type. If the patterns for the Cinema Integraph were to pass under the optical sound reader of a motion picture projector, they too would make blips and beeps and buzzes. Reversing roles, if an optical soundtrack were to pass through the Cinema Integraph, it would result in a series of computations, albeit with little mathematical value. Alongside several other 1930s experiments with film as a data medium, such as Emanuel Goldberg's Statistical Machine at Zeiss Ikon and Richard S. Morse's "data soundtracks" at Eastman Kodak, these experiments sought to automate work processes through technologies of vision, thereby relieving the handiwork of earlier clerks and "human computers" who painstakingly had to track down documents or calculate equations by hand.[16] Words, numbers, and sounds all converged on the single medium of optical film, whereupon each could translate into any of the others. Before the transcoding of all media, there was the translation of each into the others by means of formal likeness: translation by means of analogy.

The Cinema Integraph was part of a wide-ranging effort to automate the process of calculation at MIT and other top research laboratories, such as the Moore School at the University of Pennsylvania and commercial initiatives at Bell Labs and IBM. Completed in 1938 and thus several years in advance of Konrad Zuse's successful Z3, the Cinema Integraph counts as the first computer to use motion picture film—even though unlike Zuse's computer, which used punched 35 mm film to compute digitally, the Cinema Integraph used visual patterns that were entirely analog. Brown noted in an interview the limited lifespan the machine had because it was analog: "Now it was only two or three years after that that the whole digital world exploded, and that was the death of the Cinema Integraph and, of course, Differential Analyzers."[17] Where Brown saw a clear rupture, however, Wiener saw an important continuity.

The Cinema Integraph was, as Wiener liked to say, an "analogy machine" since it worked with measured quantities rather than digits. Wiener explained this succinctly by saying: analogy machines measure; digital machines count. Bush's Differential



Function films printed for the Cinema Integraph. From *The Journal of the Franklin Institute* (1940).

Analyzer was an analogy machine; it worked by measuring mechanical movements in one dimension, with all computation taking place on the basis of time, sequentially. The optical idea of computing began when Bush came to Wiener with the need to create a machine for solving partial differential equations. This method of computing required two interrelated dimensions, as Wiener explained, "in which time rates of change and the space rates of change are united by equations." Wiener's realization at the old Copley Theater was that partial differential equations thus require representation in two or more dimensions of *space*, a realization that pointed to a simple medium: "the density of a photographic negative, which varies up and down and left and right." Wiener's optical idea thus settled the problem of solving two functions, as required in harmonic analysis for signal processing, by representing them in two spatial dimensions. He recounted the discovery by saying, "if you wanted to solve a problem whose answer was distributed in more dimensions, you had to be able to represent a function in more dimensions."[18]

The patterns printed on film for the Cinema Integraph took form as regular sinusoidal curves with one half of the film shaded to form a mask. In *An Introduction to Cybernetics*, W. Ross Ashby provides a useful description of such a machine when he explains how engineers investigate electrical systems using machines designed to perform Fourier analysis, the exact process the Cinema Integraph automates:

> The engineer often investigates the nature of some unknown system by submitting it to an incessant regular change at its input while observing its output. Thus, in Fourier analysis, he submits it to prolonged stimulation by a regular sinusoidal potential of a selected frequency, and he observes certain characteristics in the output; then he repeats the test with another frequency, and so on; eventually, he deduces something of the system's properties from the relations between the input frequencies and the corresponding output frequencies.[19]

As with other analog computers, shifting the selected frequency to be tested meant shifting the setup of the machine. Changing the setup of the Cinema Integraph was another of its advantages because it required only a change in the pattern printed on the film, rather than the painstaking task of adjusting dials and levels. Yet the Cinema Integraph still required a physical change in the machine. A new analogy had to be created for every new frequency tested, a process that took time.

The optical idea became a digital idea because of this problem of speed. In order to compute the equations rapidly, Wiener had to reintroduce the problem of time. The speed of motion picture film, while faster than cardboard masks, was still a considerable limitation. The solution to this last problem was again an optical idea, but it was also a digital idea based on an analogy with the scanning of a television image:

> In television, a picture is conveyed not by pieces of silver of various opacities placed simultaneously on a film but rather by a dot of light running over the various rows of a grid point by point, and the whole grid row by row. This process, called scanning, is now familiar to anyone who has the least curiosity as to how his home television set works.[20]

The method of scanning allowed Wiener to extend the optical idea beyond the analog Cinema Integraph to a digital method using cathode ray tubes (CRTs). This was why Wiener saw continuity between "analogy machines" and digital machines where many others, including Brown, saw a marked rupture. Between Wiener's discovery in 1931 and his retrospective with Brown in 1955, Frederic Caland Williams and Tom Kilburn implemented the optical method of digital computing in the Williams-Kilburn Tube, a cathode ray tube developed in 1947 to store digital data, just as Wiener had predicted.[21] Wiener reflected, "In fact, I was convinced that the scanning technique would prove socially more important in computing machines and their close relatives than in the television industry itself. The future development of computing machines and control machines has, I believe, borne me out in this opinion."[22] Although future developments confirmed Wiener's assumption, the visual method of computing, like the Cinema Integraph, would be short lived, as magnetic tape released computers from the optical necessity and instituted a profound invisibility on the idea of the visible. Yet even these developments, which left the sphere of visibility behind, remained true to Wiener's original ideas. The reason has to do with Wiener's other emphasis: all digital computing is importantly analog as well.[23]

"Every Digital Device Is Really an Analogical Device"

The analog and digital, like all truths in a Nietzschean sense, are "illusions about which one has forgotten that this is what they are; metaphors which are worn out and without sensuous power; coins which have lost their pictures and now matter only as metal, no longer as coins."[24] Claus Pias has called this hardening of the distinction between analog and digital the "cybernetic illusion."[25] In a reversal of Nietzsche's metaphor of the coin that has lost its currency and now matters only in its materiality, no longer in its Manichaean reversibility, the cybernetic illusion strategically forgets materiality and poses only symbolic alternation, effacing the continuity of analog processes underlying digital information. Rather than forgetting the faces for the metal, it forgets the metal for the faces.

In 1950 at the Seventh Macy Conference on Cybernetics, Wiener clouded—but also confirmed—this picture of symbolic alternation by citing a coin as an illustration of the slippery distinction between analog and digital. Take, for instance, a coin toss, he says. We are accustomed to think of a coin toss in terms of a binary decision, heads or tails. Gambling and sports depend on this binary moment of chance, two possibilities with nothing in between. The coin toss has entered into games of chance based on the continually confirmed assumption that the coin will land with one of its two sides facing up. But as anyone knows from dropping a dime in the grass and finding it leaning on edge, this alternation of heads and tails is in actuality based on a probability. As Wiener points out, although the coin may land any which way, the extraordinary unlikelihood that it will land any way other than heads or tails makes it essentially digital. Its two "fields of attraction," heads and tails, largely rule out other possibilities and make it easy to forget—even sometimes necessary to forget—that the coin maintains a continuous or analog aspect.[26]

As Pias explains, the cybernetic illusion strategically forgets the edges of the coin in order to gain certain advantages by the alternation of its faces. The key to digital thinking, as John Stroud aptly stated in the same talk at which Wiener offered the coin example, is to treat objects such as coins or vacuum tubes "as if these transition states did not exist"—as if the physical continuity of the coin or the electrical voltage continuity that allows the vacuum tube to "switch" did not exist. "It is quite a good way of treating them," Stroud added.[27] Like several other participants at the conferences, Stroud, an electrical engineer for the U.S. Navy, was primarily interested in the practical applications of digital devices, how these could be used to build better and faster computers. The elimination of the in-between states—what he called "the devils . . . working somewhere in between"—was a functional consideration and, at least initially, a more or less conscious limitation of scope in order to realize certain technical possibilities.[28] The long-term outcome of this way of thinking, however, and precisely because of its effectiveness in building machines that work, has been that the in-betweens now really have been forgotten. This is not simply benign neglect but the product of an active process of forgetting, in the Nietzschean sense. Digital technologies and digital ways of thinking suppress analogical ways of thinking. As N. Katherine Hayles has shown, the Macy Conferences were tremendously influential in advancing this priority of information over materiality.[29]

In the discussion at the seventh conference, however, this process of suppression was only just getting underway. Opposing Stroud's position, an important contingent stood commanding far more than theoretical speculation about the devilish continuities underlying digital operations. As Pias notes, after World War II the gap between these two contingents "becomes increasingly large," attested to by the growing tension of the analog/digital debates. From the other side of this divide, mathematician and engineer Julian Bigelow reassessed Stroud's strategic forgetting as a willful repression, the creation of a "forbidden ground":

> [I]t does not seem to me enough to describe a digital process as being one in which there are two or more discrete levels in which you are only interested in saying whether you are at level *A* or level *B*. I think it is essential to point out that this involves a forbidden ground in between and an agreement never to assign any value whatsoever to that forbidden ground.[30]

Ralph Gerard sought to clarify this notion of the forbidden ground by arguing that it is really only "forbidden for one type of functioning," the type of functioning that goes on in the analog continuous zone.[31] Gerard, a physiologist, was interested in the analog and digital insofar as they were frames for understanding the operations of the central nervous system. In what Pias has called the "most traitorous episode" of the analog/digital debates, Gerard argued that "synapses are not acting digitally." He elaborated upon this point, claiming, "even though we find digital operations in the nervous system, this may or may not be the essential mechanism accounting for its behavior." Gerard backed up his claim by offering a view of the brain's supposed digital operations—the discrete firings of synapses—from a holistic, systemic perspective: "What is important is the total pattern of time intensity. No variation of the impulse, and whether messages go by discrete impulses or by some other mechanism which is not discrete, would essentially alter the total performance of the system."[32] Gerard's point was not to deny that certain aspects of the brain could be treated by digital analysis, but to say that even if these analyses yielded satisfactory results, they would not be capable of explaining the overall nervous system, which requires analysis of its "actual functioning . . . in the forbidden continuous zone."[33]

In response to Gerard's concerns, Bigelow rephrased his own understanding of the forbidden ground as it relates to electronic computers:

> If a device operates in an in-between zone and if that is a meaningful behavior, it seems to me one either has to throw out the term "forbidden" and admit that the zone is an acceptable one having a value, or else assume that there are as many

values as you please and therefore is a continuum of zones, in which case the digital property really has vanished and you are talking about analogical concepts.[34]

The trouble was that as much as the participants wanted to ignore the analogical domain, it continually reasserted itself. If it could be suppressed by a pragmatically minded limitation of scope, it could do so only at the expense of the sphere it eliminated. For Gerard, at least, the sphere being eliminated was that of the overall system, a particularly undesirable consequence.

Besides the problem of the forbidden ground was the problem of terminology. When engineers coined *analog* and *digital* in the early 1940s, the terms designated two classes of computing machines: the older, already established analogical machines of Bush versus the emerging electronic discrete computers being developed for the war.[35] As Warren McColluch pointed out, the distinction had not always gone by the same names, and in a sense the term *digital* had already worn away one face of this terminological coin: "They used to be called logical machines or analogical machines before the word digital appeared." J.C.R. Licklider, a moment earlier in the same discussion, seemed to reach a point of frustration with the terms altogether, exclaiming, "The names confuse people. They are bad names." For Licklider, no one looked at *analog* and *digit* and saw an opposition. Even an intelligent person would have a hard time guessing how they relate, let alone how they strictly oppose one another. If they mean simply continuous and discrete, Licklider thought, why not drop the term *digital* altogether and just call them continuous machines and discrete machines?[36]

For most of the other participants at the Macy conferences, however, the solution was not so simple. Although "continuous/discrete" described some of the differences between the machines in question, it could not capture the whole picture. If the problem with the term *digital* consisted in trying to find an appropriate name for a new function of computing machines, the problem with the term *analog* was deeper and not merely a matter of nomenclature. Although several suggestions arose for terms that might replace *digital* and be more adequate to the technological reality, such as the earlier term *logical machine* or Wiener's "discretely coded machine," nothing indicated that the term *analog* shared the same vicissitudes. This was the case, John von Neumann explained, because analogical machines and analog computers actually functioned by means of analogy. The term *analogy* was thus entirely adequate to at least part of this technological reality. Moreover, digital technologies themselves were not exempt from functioning by analogy, as Licklider explained in pointing out that one digital process could be "the analogue of another digital process, and therefore really analogical." A similar idea prompted

Wiener to say, "Every digital device is really an analogical device." For Wiener, the basis of all computer modeling was analogy. Without analogical similarity, devices would refer to nothing at all and would have no reason to exist. Analogy was the reason for their operations and the guarantee of their effectiveness.[37]

As Wiener stresses, all machines maintain an analog dimension. Being analog in this sense means having the ability to traverse spheres, not only between different languages and codes but between different types of movements, even between the digital movements of on/off switches and the analog continuous movements of gears and cylinders. And this is the realization Wiener had when he devised an optical idea of computing. Visualizations—movements of and within the image—can pass into the sphere of mechanical movements, those of and within the machine. Analogies make up an interface of machine language with machines, the coupling of cinematics and kinematics.

The Coupling of Cinematics and Kinematics

Bush's Differential Analyzer performed computations based on an analogy between moving parts and computed quantities. Wiener explains: "Bush had made, with great success, machines for solving ordinary differential equations, analogy machines, because quantities in those machines were represented by other quantities, not by numbers—for example, by rotations on a shaft."[38] What this meant at its core was that machine movements could be translated into computations. The rotations of a shaft or the turning of a gear could provide analogies for a process of calculation. Even if digital computing would surpass analog computing, it remained clear that computations and machine movements were interchangeable, that computations could control machine movements, and, based on the optical idea, that cinematics could control kinematics. Wiener made the case explicitly when he said about his discovery of the optical idea at the old Copley Theater, "it really led quite directly to the present status of computing machines and indirectly to control machines and automatization."[39] Brown echoed the idea when he admitted that his work with servomechanisms (devices that can monitor their own movements and correct for errors) stemmed from his doctoral thesis on the Cinema Integraph.[40]

The connection between optics and machine movements is even less surprising in light of the correspondences drawn in several recent studies between cinema and machine kinematics.[41] The study of kinematics concerns the analysis and synthesis of machine movement but also applies to organic and human physiology, as seen in Étienne-Jules Marey's work with animal mechanism and as Friedrich Kittler shows through the work of Wilhelm Weber and Eduard Weber in Germany.[42] With a hint of nationalistic pride, Kittler points out that the Webers were performing cinematics nearly half a century before Marey and Eadweard Muybridge, if by slightly different means. At a time when daguerreotypy and Talbot's calotypes required exposure times far in excess of that necessary to capture living bodies in movement, the Webers adopted a method of letting the leg provide its own account, using corpses to print the body's fulcrums of movement. Kittler argues, "Cinematics in the French sense of the word, which as of 1830, and at Ampère's instigation, calculates transversal and rotational movements of steam engines, becomes cinematics in the modern sense: it calculates virtual movements in virtual, that is, visualizable spaces."[43] Ampère's cinematics, which through a long circuit of research in Germany becomes machine kinematics, and passing through the physiological studies of the Webers and later Marey and Muybridge becomes cinematics in the modern sense, circles back to kinematics through the work of Wiener and Brown on the optical idea of computing.

The connection between cinematics and kinematics runs even deeper. In a study of the machine kinematics of the nineteenth century, Helmut Müller-Sievers makes an incisive analogy between film cameras and lathes: "Just as we can think kinematically of the [Galerie des Machines] as a minimal moving wheel, we can think of the film camera as a lathe that carves light onto film."[44] Müller-Sievers elaborates upon these "light lathes" in terms of their precise kinematics:

> In the language of kinematics and its cylindrical embodiments, cinematography begins when the translational motion of light along the axis of the lens joins the rotational motion of film that is exposed to it. Film cameras and projectors are light lathes that, like their metal counterparts, introduce an element of abstract "work" into the production and consumption of images.[45]

The comparison between lathes and film cameras marks an important reversal in common understandings of the lens as an extension or simulation of the eye. Characterizing the film camera as a "light lathe" means that the source of translational, straight-line movement is to be compared to an "iron hand," as we find in Müller-Sievers's quotation from Robertson Buchanan, dated 1841 in the midst of the revolution in lathe technologies:

> It was this holding of a tool by means of an iron hand, and constraining it to move along a surface of the work in so certain a manner, and with such definite and precise motion, which formed the great era in the history of mechanism, inasmuch as we thenceforward became possessed, by its means, of the power of operating alike on the most ponderous or delicate pieces of machinery with a degree of minute

> precision, of which language cannot convey an adequate idea; and in many cases we have, through its agency, equal facility in carrying on the most perfect workmanship in the interior parts of certain machines, where neither the hand nor the eye can reach.[46]

In this notable reversal of our usual sense of technological extensions, the lens is "an iron hand" that allows work to go on "where neither hand nor the eye can reach." In Buchanan's imaginings, we can now go into those "innermost holes" that elude us, just as the cameras of Marey and Muybridge had done, both eyes and hands reduplicated.

This automation of the hand leads back to the concept of calculation at its very source and begins to explain why the optical idea of computing joins together the work of the hand and the work of the eye. The concept of calculation derives from ancient Greek pebble boards, extensions of the hand. The Latin term *calculus*, from which Renaissance concepts of mathematical calculus and calculation derive, means a small stone, from the Greek χάλιξ, *khaliks*, pebble. This Greek root helps explain another of its modern take-ups, *calcium*. In a nineteenth-century study, James Gow recounts the history of "pebble symbolism" in early Greek calculation as having developed alongside finger symbolism at the same time written symbols were being developed to supplement both, likely taking form initially as strikes on the ground.[47] Such boards acted as supports for counting numbers that were too great for finger symbolism alone. When there were not enough fingers to go around, hands had to outsource some of the work of calculation to the eyes.

The same can be said of the Cinema Integraph, where an extension of the eye—the optical idea of computing—comes to the aid of Bush's Differential Analyzer and its deficient "iron hands." The history of automation in this sense involves the folding of cinematics and kinematics, where advances in imaging serve to automate machinery, as seen in Wiener's optical computing machine and Brown's servomechanisms laboratory. As the example of Greek pebble boards suggests, this folding has a long history, including the role of optics in precision mechanics—as for instance in the role of telescope optics in the development of precision tools—and continuing into the twentieth century with the development of cinema, computing machines, and robotics.[48]

Emphasizing this deftly imbricated relationship between cinematics and kinematics underscores an important refrain that software studies has brought to bear on the study of digital cinema. Gabriel Menotti Gonring makes an important restoration of the materiality of digital imaging by arguing that digital images are "executable images" and "stand for" the algorithms that convey them.[49] Computer monitors and television screens, on this view, "express the physical organization of the machine as information."[50] Far from being immaterial, information is the expression in materiality of another materiality, which makes up its physical substratum. However, this is to say something more. The coupling of cinematics and kinematics raises a question about the status of the human vis-à-vis technologies of calculation and vision. If computer imaging operates on the same basic principles as abacuses and pebble boards, as Gonring suggests, a key distinction nonetheless remains: the operations of pebble-based devices can be seen and grasped clearly, while those of computers cannot. While obvious, this is no simple problem, and cybernetics had to create a new concept in order to deal with it.

The Black Box of the Digital Image

"A fundamental property of machines," Ashby states, "is that they can be coupled."[51] Machine kinematics, following Reuleaux's famous formulation of the machine as a "chain" of "kinematic pairs," is the science of this essential duality at the basis of all mechanisms.[52] A bolt must always include a nut, and is not a bolt without it. A lever is not a lever without its fulcrum. Understanding how a machine works involves understanding the nature of its coupling. In Ashby's words, "Two or more whole machines can be coupled to form one machine; and any one machine can be regarded as formed by the coupling of its parts, which can themselves be thought of as small, sub-, machines."[53] As the complexity of a machine increases, the ability to observe its operations diminishes. The relationship between the smaller submachines and the overall performance becomes more obscure. When this happens, one must make do with an incomplete picture. Cybernetics calls this incomplete picture the "Problem of the Black Box."[54]

Ashby provides an example. Suppose an unknown Box has fallen from the heavens. We know nothing of its origin, nature, or use. To ascertain what the Box does, if anything at all, we have to test it. One of the first tools Ashby gives his imaginary researcher is a camera to photograph the behavior of the Box (we may assume that, for it to be most effective, the camera can capture moving images). Photography and cinematography become ways to observe the different behaviors of the Box, and they allow the researcher to store past behaviors, compare them, and glean patterns. In doing this, Ashby explains, the experimenter joins together with the Box in a fundamental way: "By thus acting on the Box, and by allowing the Box to affect him and his recording apparatus, the experimenter is *coupling* himself to the Box, so that the two together form a system with feedback."[55]

If human beings can couple themselves with machines, it is because from the perspective of cybernetics they share functional similarities. The organization of the living and the organization of machines is not a difference of kind but one of degree, an idea that Wiener liked to consider with what he saw as a not-so-wild speculation about teleportation: "[T]he fact that we cannot telegraph the pattern of a man from one place to another seems to be due to technical difficulties, and in particular, to the difficulty of keeping an organism in being during such a radical reconstruction. The idea itself is highly plausible."[56] Organisms, as Wiener sees it, are in actuality highly complex messages, and these messages can take different forms depending on the material composing them, whether living or nonliving, analog or digital. Whatever form they take—as human beings, animals, or machines—these complex "messages" share analogous components such as sense organs and effector organs. Sense organs, such as eyes, ears, cameras, photocells, and microphones, allow for input. Effector organs, such as the muscles of living creatures and the mechanical design of machines, allow for output.[57] As Ashby explains, when an experimenter investigates the performance of some unknown device, the experimenter's sense inputs receive information from the machine's system of outputs. Conversely, the experimenter's actions function as outputs that the machine receives as inputs, forming a feedback loop: "Every real system has an indefinitely large number of possible inputs—of possible means by which the experimenter may exert some action on the Box. Equally, it has an indefinitely large number of possible outputs—of ways by which it may affect the experimenter, perhaps through recording instruments."[58] If the Black Box does not record its own output—for instance, as with a computer that is not connected to a monitor—then the experimenter must rely on observation alone or make use of supplemental means of recording the output such as a gauge or a camera.

The goal of testing the Black Box is to find regularities in its behavior, patterns in its output that can reveal something about the internal structure hidden from view. The experimenter is searching for something "similar in pattern"; that is, an appropriate analogy that can represent what cannot be seen. Ashby's first example of such an analogy is a photographic negative:

> A photographic negative and the print from it are, so far as the pattern of the picture is concerned, isomorphic. Squares in the negative appear as squares in the print; circles appear as circles; parallel lines in the one stay parallel in the other. Thus certain *relations* between the parts within the negative appear as the same *relations* in the print, though the appearances so far as brightness is concerned are different, exactly opposite in fact. Thus the operation of changing from negative to print leaves these relations unaltered.[59]

The patterns need not be visual. Mathematical equations can have isomorphism with objects in motion, proven by these equations being automated in analog computers using mechanisms to calculate the isomorphic paths of projectiles. As Martin Heidegger argues in "The Age of the World Picture," however, even mathematical equations are importantly visual. Conceiving of a projectile in motion as a set of points in space is tantamount to conceiving of it as a picture.[60] A world that is calculable is a world capable of being pictured, a world transformed into an image. In this sense, Ashby's provision of a camera to his imaginary researcher is no mere coincidence. To understand the hidden workings of the Black Box is to get a picture of them.

Problems arise, however, when the internal workings of the Box resist clear representation, as when the machine is very complex or when it withholds part of itself from coupling. The machine can then "beat" the observer, as Ashby says, by its largeness:

> I shall use the words "very large" to imply that some definite observer is given, with definite resources and techniques, and that the system is, in some practical way, too large for him; so that he cannot observe it completely, or control it completely, or carry out the calculations for prediction completely. In other words, he says the system is "very large" if in some way it beats *him* by its richness and complexity.[61]

The characterization "very large system" refers not to the mass of the system but to the complexity of its interconnections. "Very large systems" can be very small, an idea that Heidegger intuited in his concept of the *gigantic*. A system that is too large can be dealt with in several ways. The researcher can specify it "statistically," which amounts to understanding it in terms of manageable rules, with the outcome resulting from a process of sampling. In this sense, the observer gives up an understanding of the system in its full complexity in order to gain an understanding of its dominant pattern. But a system of prodigious complexity can be dealt with in another way, as Ashby exclaims: "[I]t is, in a sense, possible for an observer to specify a system that is too large for him to specify!"[62] This becomes possible when the process of specifying a system is *supplemented* by another system. Such technological supplements—as when a computer allows us to specify a system outside the bounds of human sense and intellect—resolve complexity and allow observers to understand systems that would "beat" them.

When electronics outstrip human means of observing their inner workings, this happens on the same basis: they are supplemented, indeed produced, by machines that perform actions that people cannot. For Ashby, *designed machinery* is proof that the theory of Black Boxes is "practically coextensive with that of everyday life."[63] And this is where cybernetics offers its most fundamental insight into the distinction between analog and digital technologies, one particularly relevant to the film-theoretical problem of digital cinema.

From a cybernetic perspective no distinction can be made between isomorphic electrical, mechanical, and mathematical systems, as Ashby says: "Clearly no one of these three systems has priority; any can substitute for the others."[64] Yet this is precisely what several important cinema scholars deny in addressing analog and digital images. D.N. Rodowick makes a representative argument for why digital imaging and traditional celluloid cinematography are merely *similar* and *not isomorphic*:

> The chemical contents of a 35mm frame (the grain of the image) are not equivalent to 12 million pixels. Only in digital devices can picture elements be quantified in this manner. . . . It is more precise to say that it would take 12 million pixels to make an electronic image perceptually *similar* to a 35mm photographic image.[65]

To get to the bottom of this distinction, we need to recall why Ashby considers Black Boxes to be ubiquitous:

> At first we are apt to think, for instance, that a bicycle is not a Black Box, for we can see every connecting link. We delude ourselves, however. The ultimate links between pedal and wheel are those interatomic forces that hold the particles of metal together; of these we see nothing.[66]

In a similar way, Ashby notes, bridge builders deal only with part of the system of a bridge—for instance, the girders—but not all the atoms composing the materials. An isomorphism can exist between the pedals of two different bicycles made of two different materials or between two different bridges made of two different materials because the different parts are "equal" and, as Ashby stresses, "so alike that an accidental interchange of them would be subsequently indetectable, at least by any test applied to their behaviours."[67] The widespread practices in the film industry of shooting on film, editing on digital nonlinear software, exporting again to film, and distributing movies shot on celluloid in various digital formats, stand as testaments to this functional equality between analog and digital cinema. If all objects can be considered Black Boxes in an important sense, and if digital and analog imaging are functionally identical even at the level of their industrial production, then what makes digital cinema so different from traditional analog imaging that scholars would insist on this difference?

The reason, from a cybernetic perspective, is that, like the bridge builder who can work without understanding the individual molecules of the bridge, scholars and moviegoers have rarely needed to pay attention to the chemical composition of celluloid. Its composition has seemed "natural" enough or "accidental" enough for one to treat it simply as a given. The digital image changes all this because its composition is predicated on human design at a more basic level. The degree of its matter *that matters* runs deeper. The digital image institutes a Black Box in the order of the visible, an unobservable system of human design inside a visibility. If, as Ashby explains, even a doorknob is a Black Box—if a device simple enough for anyone to understand can be a Black Box—then whether engineers can explain what is "in" the Black Box of the digital image hardly matters, because any explanation requires a supplement. This is the meaning of "the end of cinema." What ends is a certain commensurability between the human and cinema in their coupling.

Circuits of Hand and Eye

For Wiener, the history of computing makes a singular leap not with the introduction of the discretely coded machine but earlier, when cinematics enter the process of calculation with the optical idea of computing. As Wiener sat during the intermission at the old Copley Theater, in the age-old experience of watching human actors perform a play of human magnitude, he alighted on the same optical technique that was presently wiping out the last vestiges of silent film accompaniment through the optical transcription of sound on film, the "automatization" of work formerly done by hand by means of a technical extension of the eye. Translating the fluctuations of sound and the movements of computing machines into the common medium of visualizable space meant that they were all translatable in terms of one another; more important, it meant that they were more precisely measurable. This emphasis on finer materialities—and not on the creation of immaterialities—is the most important precondition of digital media because the greater the precision in measurement the more practical it is to forget the "devils working in between." That is, the more finely divided the grid, the more precise the analogy.

In an unexpected confirmation of Wiener's belief that the optical idea would prove socially more important in computing machines than in visual media, digital computing itself made a singular leap when cinematics intervened in the production of transistors. In 1960 Jean Hoerni at Fairchild Semiconductor devised the planar approach to manufacturing integrated circuits, a process that historian Christophe Lécuyer has called "the most important innovation in the history of the semiconductor industry."[68] Laying out all junctions on a flat topography allowed the industry to fully exploit earlier lens and mask techniques to print semiconductor patterns directly on a wafer's surface, a technique that led directly to the integrated circuit as a planar component integrating "transistors, diodes, capacitors, and resistors into the silicon crystal."[69] The basis of current digital computing, in this sense, relies on a continuous design open to a total field of view that allows it to be printed photolithographically—not a discrete design as in earlier mesa transistors, which separated collector and emitter on different sides inaccessible from a single optical standpoint.

In keeping with Wiener's insight that the primary importance of the optical idea would be for machines and not for human spectators, Leroi-Gourhan reimagined the faculties of human cognition four years after Hoerni's discovery from the decentered perspective of contemporary electronic machines. Precisely because of the problem of largeness, in Ashby's sense, these machines newly troubled the human sciences:

> The artificial brain of course is still in its infancy, but we can already be sure that it will be more than just a nine days' wonder with limited applications. To refuse to see that machines will soon overtake the human brain in operations involving memory and rational judgment is to be like the Pithecanthropus who would have denied the possibility of the biface, the archer who would have laughed at the mere suggestion of the crossbow, most of all like the Homeric bard who would have dismissed writing as a mnemonic trick without any future. We must get used to being less clever than the artificial brain that we have produced, just as our teeth are less strong than a millstone and our ability to fly negligible compared with that of a jet aircraft.[70]

Reaching the brink of the all-purpose computing machine at this point in the book, however, Leroi-Gourhan chooses to turn away from the revolution in electronics. He shifts his focus from the technical outgrowths of cybernetics to the paleontology of symbols, returning to the question of aesthetics and of the human.

Following Leroi-Gourhan, Jacques Derrida takes up the cybernetic perspective by invoking the notion of *program* to explain the entirely nonanthropocentric history of the human adventure as the movement of *différance*, "as a stage or an articulation in the history of life."[71] As an epoch in human history, the cybernetic perspective is situated at what Derrida points to as the closure of metaphysics, becoming possible at that moment when certain "human" functions redoubled in the domain of machines—intelligence, memory, and rational judgment—call into question the privilege and uniqueness of the human experience. Similarly to Leroi-Gourhan, Derrida turns his attention to the history of human language even while noting the necessity of thinking it anew in terms of the coupling of hand and face:

> The history of writing is erected on the base of the history of the *grammè* as an adventure of relationships between the face and the hand. Here, by a precaution whose schema we must constantly repeat, let us specify that the history of writing is not explained by what we believe we know of the face and the hand, of the glance, of the spoken word, and of the gesture. We must, on the contrary, disturb this familiar knowledge, and awaken a meaning of hand and face in terms of that history.[72]

Part of disturbing this familiar knowledge in Leroi-Gourhan's project is reimagining the entire history of life as following a program, each stage of which involves a coupling along the same model as that of hand and face. Biological organisms from the earliest single-cell life forms organize dialectically into two poles, first toward movement, then toward liberation of the forelimbs, and finally toward the exteriorization of tools. In turning back to the question of aesthetics upon reaching the brink of digital computing and in turning back toward the metaphysical adventure of Western philosophy, Leroi-Gourhan and Derrida use the cybernetic perspective as a tool to open up the humanities while leaving the offspring of cybernetics for another reading.

Just as, in Leroi-Gourhan's reading, biological organisms are divided along the anterior field of responsiveness into poles corresponding at an advanced stage of their coupling to hand and face, advanced machines are organized in terms of what Wiener calls sensors and effectors—along a significant line of development in terms of optics and mechanics. In a sense, the sphere of technics has a human dimension and a nonhuman dimension, as seen in the connotations of picturing, often associated with human vision and its many metaphors with intelligence, and calculation, expressing the cold rationality of machines. Calculation and picturing mirror within technics the relationship of hand and face, eliminating the intervening agency of the human both in terms of manual and intellectual labor.

The historical tipping toward the digital, rather than marking the end of the analog, marks a new era in technologies of analogy, a new era in the folding of picturing and calculation that is also an unprecedented moment in the history of the human in its coupling with technics. The moment is unprecedented not because it involves a further extension of the human, in Marshall McLuhan's sense, but because it calls into doubt the necessity of the human in the coupling of picturing and calculation. Digital cinema raises the question of a cinema without people, but not because cinematic images had never before exceeded human use and intelligibility. Instead, as Wiener intuited, it reveals that cinematics proceed without us, interfacing with kinematics as much as they ever interfaced with crowds of human spectators.

Notes

Research for this article was supported by a Mellon/ACLS Dissertation Completion Fellowship and a research award at the MIT Institute Archives and Special Collections. I thank the editors at *Grey Room* as well as Chad Vollrath, Andrew Ritchey, and Mark Martinez for their kind input on several drafts.

1. Definition of *cinématique* from William Thomson and Peter Guthrie Tait, *Treatise on Natural Philosophy*, pt. 1, new ed. (Cambridge, UK: Deighton, Bell, 1888), vi. "C'est à cette science où les mouvements sont considérés en eux-mêmes tels que nous les observons dans les corps qui nous environnent, et spécialement dans les appareils appelés machines, que j'ai donné le nom de *cinématique*, de κίνημα, *mouvement*." André-Marie Ampère, *Essai sur la philosophie des sciences* (Paris: Bachelier, 1838), 52; emphasis in original.

2. Friedrich Kittler, "Man as a Drunken Town-Musician," *MLN* 118, no. 3 (April 2003): 644.

3. André Leroi-Gourhan, *Gesture and Speech* (Cambridge, MA: MIT Press, 1993), 20; emphasis in original.

4. Lev Manovich, *The Language of New Media* (Cambridge, MA: MIT Press, 2001), 20.

5. Gordon S. Brown and Norbert Wiener, "Automation, 1955: A Retrospective," *Annals of the History of Computing* 6, no. 4 (October 1984): 374.

6. Brown and Wiener, "Automation," 379.

7. Wiener, *I Am a Mathematician* (New York: Doubleday, 1956), 26. For more on the Copley Theater and the history of theaters in Boston more generally, see Donald C. King, *The Theatres of Boston: A Stage and Screen History* (Jefferson, NC: McFarland, 2005).

8. Wiener, *I Am a Mathematician*, 112.

9. For more on Brown's work with Hazen, see David A. Mindell, *Between Human and Machine: Feedback, Control, and Computing before Cybernetics* (Baltimore: Johns Hopkins University Press, 2002), 163–164.

10. See H.L. Hazen and G.S. Brown, "The Cinema Integraph: A Machine for Evaluating a Parametric Product Integral," *Journal of the Franklin Institute* 230, no. 1 (July 1940): 19–44. The second part of the article appeared in the following month's issue. H.L. Hazen and G.S. Brown, "The Cinema Integraph: A Machine for Evaluating a Parametric Product Integral," *Journal of the Franklin Institute* 230, no. 2 (August 1940): 183–205.

11. Gordon Stanley Brown, interview with Alex Pang, 24 July 1985, 35, in Gordon Stanley Brown Papers, MIT Institute Archives and Special Collections, MC 24, Box 31.

12. See Deac Rossell, "A Chronology of Cinema, 1889–1896," *Film History* 7, no. 2 (Summer 1995): 115–236.

13. See John Belton, "The Origins of 35mm Film as a Standard," *JSMPTE* 99, no. 8 (August 1990): 652–661. In the early 1890s, Dickson ordered standard Kodak 70 mm film reels and simply cut the film in half lengthwise so he could get twice the footage at the same cost. The practice became so common that Kodak soon offered 35 mm as a standard gauge.

14. Hazen and Brown, "The Cinema Integraph," 29; emphasis adjusted.

15. For an excellent history of Pfenninger's experiments in synthetic sound, see Thomas Y. Levin, "'Tones from Out of Nowhere': Rudolph Pfenninger and the Archaeology of Synthetic Sound," *Grey Room* 12 (Summer 2003): 32–79.

16. Michael Buckland, *Emanuel Goldberg and His Knowledge Machine: Information, Invention, and Political Forces* (Westport, CT: Libraries Unlimited,

2006); and Richard S. Morse, "Rapid Selector-Calculator," U.S. Patent 2,295,000 (8 September 1942; filed 1938). Morse mentions that the "data soundtrack" might be better termed a "frequency track" because the invention does not relate to the reproduction of sound. Nonetheless, the technology would continue to be called a "soundtrack" in subsequent literature. For more on the manual task of computing, see D.A. Grier, *When Computers Were Human* (Princeton, NJ: Princeton University Press, 2005).

17. Brown, interview, 36.

18. Brown and Wiener, "Automation," 380.

19. W. Ross Ashby, *An Introduction to Cybernetics* (New York: John Wiley and Sons, 1956), 47.

20. Wiener, *I Am a Mathematician*, 137.

21. See Charlie Gere, "Genealogy of the Computer Screen," *Visual Communication* 5, no. 2 (2002): 141–152.

22. Wiener, *I Am a Mathematician*, 137–138.

23. Wiener states, "Every digital device is really an analogical device." *Transactions/Protokolle*, vol. 1 of *Cybernetic / Kybernetik: The Macy-Conferences 1946–1953*, ed. Claus Pias (Zurich: Diaphanes, 2003), 158.

24. Friedrich Nietzsche, "From *On Truth and Lie in an Extra-Moral Sense*," in *The Portable Nietzsche*, ed. and trans. Walter Kaufmann (New York: Viking Penguin, 1982), 46–47.

25. Pias, "Analog, Digital, and the Cybernetic Illusion," *Kybernetes: The International Journal of Systems and Cybernetics* 33, no. 2 (2004): 8.

26. See Ralph W. Gerard, "Some of the Problems Concerning Digital Notions in the Central Nervous System," in *Cybernetics: Circular Causal and Feedback Mechanisms in Biological and Social Systems*, ed. Heinz von Foerster (New York: Josiah Macy Jr. Foundation, 1949–1953), 21–22. This volume contains transcripts of the seventh Macy conference.

27. John Stroud in *Cybernetics*, 30.

28. Stroud's thoughts on the matter are worth quoting: "I know of no machine which is not both analogical and digital, and I know only two workable ways of dealing with them in my thoughts. I can treat them as analogical devices, and if this is a good approximation I am happy. I can treat them as digital, and if this approximation works I am happy. The devils are generally working somewhere in between, and I cannot understand how they are working accurately." Stroud in *Cybernetics*, 28.

29. N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 1999), esp. ch. 3.

30. Julian Bigelow in *Cybernetics*, 35.

31. Gerard in *Cybernetics*, 47.

32. Gerard in *Cybernetics*, 17, 46. See also Pias, "Analog, Digital, and the Cybernetic Illusion," 4.

33. Gerard in *Cybernetics*, 46.

34. Bigelow in *Cybernetics*, 47.

35. For more on analog computing, see Charles Care, *A Chronology of Analog Computing*, Computer Science Research Report 249 (Coventry, UK: University of Warwick Press, 2006).

36. Warren McColluch and J.C.R. Licklider in *Cybernetics*, 43.

37. For Wiener's suggestion, see *Cybernetics*, 36. For Licklider's comment, see *Cybernetics*, 32. For von Neumann's description of analog computing, see John von Neumann, *Theory of Self-Reproducing Automata*, ed. Arthur W. Burks

(Champagne: University of Illinois Press, 1966), 35.

38. Brown and Wiener, "Automation," 379.

39. Brown and Wiener, "Automation," 380.

40. An earlier example, and forerunner of the Cinema Integraph, was Brown and Hazen's Automatic Curve Follower, which used cinematic patterns to control kinematic movements. The device consisted of a photoelectric curve follower, illuminated by a bright lamp, which translated the ordinates of a graph into the angular displacement of a shaft controlling a tracking head. G.S. Brown with H.A. Hazen and J.J. Jaeger, "An Automatic Curve Follower," *Publications from the Massachusetts Institute of Technology, Contributions from the Department of Electrical Engineering*, no. 124 (December 1936), in MIT Institute Archives and Special Collections, MC 24, Box 28, Folder 1,143. See also Mindell, 163–164.

41. See, for instance, Lynda Nead, *The Haunted Gallery: Painting, Photography, Film c. 1900* (New Haven, CT: Yale University Press, 2007). Nead compellingly lays out developments in art and film alongside developments in the machine sciences.

42. See E.J. Marey, *La machine animale: Locomotion terrestre et aérienne*, ed. Quatrième (Paris: Baillière, 1886); and Kittler, 644–652.

43. Kittler, 643.

44. Helmut Müller-Sievers, *The Cylinder: Kinematics of the Nineteenth Century* (Berkeley and Los Angeles: University of California Press, 2012), 42.

45. Müller-Sievers, 118–119. Müller-Sievers makes a further connection between the kymograph and cinema, thus also the folding of kinematics and cinematics: "The emergence of the cinema belongs in the trajectory of the '*méthode graphique*,' which we have already encountered as the driving force behind the passive turning of kymograph's cylinder" (118). Dagognet makes the same connection between cinematics and kinematics, relating imaging technologies back to James Watt's gauge for steam engines and Thomas Young's cylinder axis. See François Dagognet, *Etienne-Jules Marey: A Passion for the Trace*, trans. Robert Galeta (New York: Zone Books, 1992), 31–32.

46. Robertson Buchanan, *Practical Essays on Mill Work and Other Machinery*, 3rd ed. (London: John Weale, 1841), 401. See Müller-Sievers, 93–94.

47. James Gow, *A Short History of Greek Mathematics* (1884; New York: Cambridge University Press, 2010), 29.

48. See Maurice Daumas, "Precision Mechanics," in *History of Technology*, vol. 4, ed. Charles Singer (New York: Oxford University Press, 1958), 379–416.

49. Gabriel Menotti Gonring, "Executable Images: The Enactment and Distribution of Movies in Computer Networks," *Velvet Light Trap* 70 (Fall 2012): 49–58.

50. Gonring, 50.

51. Ashby, 48.

52. See F[ranz] Reuleaux, *The Kinematics of Machinery: Outlines of a Theory of Machines*, trans. and ed. Alexander B.W. Kennedy (London: Taylor and Sons, 1876).

53. Ashby, 110.

54. Ashby capitalizes "Black Box" throughout, and I have chosen to adopt this convention while discussing his writings on the topic.

55. Ashby, 87; emphasis in original.

56. Wiener, *The Human Use of Human Beings: Cybernetics and Society* (Boston: Houghton Mifflin, 1954), 104.

57. In the language of cybernetics, what I call cinematics and kinematics are

referred to as receptors and effectors. Wiener gives several examples to illustrate how the sense organs of machines are analogous to the sense organs of the living: "But modern automatic machines such as the controlled missile, the proximity fuse, the automatic door opener, the control apparatus for a chemical factory, and the rest of the modern armory of automatic machines which perform military or industrial functions, possess sense organs: that is, receptors for messages coming from the outside. These may be as simple as photoelectric cells which change electrically when a light falls on them, and which can tell light from dark, or as complicated as a television set." Wiener, *The Human Use of Human Beings*, 23.

58. Ashby, 87.

59. Ashby, 94.

60. Martin Heidegger, "The Age of the World Picture," in *The Question Concerning Technology and Other Essays*, trans. William Lovitt (New York: Garland, 1977), 115–154.

61. Ashby, 61–62; emphasis in original.

62. Ashby, 64.

63. Ashby, 110.

64. Ashby, 96.

65. D.N. Rodowick, *The Virtual Life of Film* (Cambridge, MA: Harvard University Press, 2007), 119; emphasis in original.

66. Ashby, 110.

67. Ashby, 102.

68. Christophe Lécuyer, *Making Silicon Valley: Innovation and the Growth of High Tech, 1930–1970* (Cambridge, MA: MIT Press, 2006), 150.

69. Lécuyer, 155.

70. Leroi-Gourhan, 265.

71. Jacques Derrida, *Of Grammatology*, trans. Gayatri Chakravorty Spivak (Baltimore, MD: Johns Hopkins University Press, 1997), 84.

72. Derrida, 84.