Film as the First Universal Data Medium

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In describing the single-memory, stored-program computer architecture that would come to be known by his name, John von Neumann included among the suitable media for storing instructions motion picture film:

> These instructions must be given in some form which the device can sense: Punched into a system of punchcards or on teletype tape, magnetically impressed on steel tape or wire, *photographically impressed on motion picture film*, wired into one or more fixed or exchangeable plugboards – this list being by no means necessarily complete. (von Neumann [1945] 1993, 33; Kirschenbaum 2008, 27; emphasis added)

Von Neumann's 1945 report on the EDVAC came at the tail end of film's efficacy in computing. Two years later in his "Lecture on the Automatic Computing Engine," Alan Turing would strike down the idea of using film for its being uneconomical even before ruling it out because it could not provide storage that was erasable (Turing [1947] 2004, 380). Although Turing noted another technology used in visual reproduction, the cathode-ray tube, as the likely "ultimate solution," neither motion picture film nor the television component would provide storage for the von Neumann architecture, as that role would be fulfilled by magnetic cores and later silicon (see relatedly Chun 2008; Gaboury 2021). But to disregard film as a dead-end in the history of computing is to miss the many influences that developments in photography and film have had on the advancement of electronics and semiconductors (Stine 2019). Moreover, from a media-archaeological perspective, there is much to be gained from excavating early-twentieth-century instances of film being applied to problems in data processing and storage because a case can be made that film was in fact the first universal medium.

Before digital computers and graphical user interfaces, film was the most readily available means of storing image, sound, text, and data and coordinating between them. Film provided a computing and control medium, means of document storage and retrieval, and ways of interacting with data, in both experimental and established systems between the 1930s and 1960s, that would prefigure many of the functions of later computers and serve as inspiration for porting those functions from celluloid to silicon. The widespread availability of film, owing to the popular demand for motion pictures, made it an attractive medium for shoring up some of the inadequacies of its predecessor and rival, paper, which was used as a substrate for coding and printout in the form of paper cards and paper tape but was not as durable or amenable to applications with new electrical systems as was film (see Gitelman 2014). Film enabled the automatic transcoding between mechanical movement, light, and electricity, and through these the reproduction and translation of images, sounds, texts, and computational coding systems.

Film came to be used in a wide range of data practices in the period of transformation that Colin Koopman has called "the long 1920s," when census data, employment forms, medical and health records, and racialized credit information coalesced into an "informational personhood" that gave rise to the later growth of information theory with the writings of Claude Shannon and Norbert Wiener (Koopman 2019, x). Paper remained the primary means of data input, with forms and checkboxes serving as data-collection formats. But like the US national census records in the 1880s, these forms became so numerous that they exceeded effective means of filing and data processing, pushing efforts to automate practices of form reading. Herman Hollerith's solution to the census problem was, famously, to use punched cards capable of being tabulated by machine, inspired by the railway practice of the "punch photograph," where a train operator would use a punch card to indicate hair color, eye color, etc., to indicate that a passenger had paid (Hollerith 1971). Hollerith understood his census tabulator to allow for a kind of pictorial impression of mass population data. Inventors and scientists regarded motion picture film similarly as an ideal medium for comprehending the piles of paper data being collected in medicine, insurance, and policing. To the extent that it was implemented, film accelerated and expanded data processing, substituting data operations for some of the labor of data practices. Even in its failures, it is an important prefiguration of today's coordinated systems of universal digital data, and offers historical reference points for the cultural and political hazards of surveillance techniques.

In what follows, I offer a breakdown of the three major ways film was used as a data medium, which correspond to Friedrich Kittler's three media functions of storage, transmission, and data processing (2009, 30). Film was first and foremost a storage medium capable of reproduction, a feature noted variously by film theorists such as André Bazin ([1945] 1967), who saw in it a deep potential to preserve likeness against the passage of time, and information scientists such as Paul Otlet ([1901] 1990), who envisioned its pictorial detail, in the form of microfilm, as a means of preserving documents. Through its interaction with and influence on electrical technologies, such as photomultipliers, film was also integral to systems of data transmission, where through the process of transduction from light into electricity, film became the support for sending data through information systems. Lastly, film enabled data processing in early analog and digital computers, while also coming into use in early automation systems. As I will show, it is in acting as a coordinating point for these three media functions that film earns consideration as a proto-computational medium and a testing ground for automating twentieth-century data practices.

Durable, Flexible, and Transparent

The conditions for film's use in a number of different data practices were set at the medium's beginning. Durable, flexible, and transparent, film could withstand repeated mechanical action and receive the imprint of nearly any visual design. These properties were discovered, as with many inventions in the history of media, through a combination of accident and scientific experimentation. As Deac Rossell relates, the discovery of celluloid, created by soaking cotton or wood fibers in nitric acid and a suitable solvent, "led directly to the formation of the field of organic chemistry" and ushered in a range of new chemical products (1998, 63). The German-Swiss chemist Christian Friedrich Schönbein, in a letter to Michael Faraday in 1846, extolled the virtues of paper created through this process, saying, "I have of late also made a little chemical discovery which enables me to change very suddenly, very easily and very cheaply common paper in such a way as to render that substance exceedingly strong and entirely water proof" (emphasis in original; Faraday 1991, 477; as cited in Rossell 1998, 58). The addition of photosensitive emulsions to cellulose would take a different route initially, with collodion, or nitrocellulose gel, being used in wet-plate photography, such as in the inexpensive tintypes popularized during the American Civil War. It was only a small step, however, to propose that this material, which was used – dangerously, given its flammability – for durable objects such as dental plates, knife handles, and piano keys, could leave behind the glass plates of early photographic processes and become, as Daniel Spill presented to the London Photographic Society, "a flexible and structureless substitute for the glass negative supports" (as cited in Rossell 1998, 63). Liberating the photographic emulsion from rigid glass plates would lead to the introduction of roll film and roll-film holders, bringing together the flexible, durable medium of celluloid with a new economical form of storage and mechanism of transport. Storage and transport, in turn, would lay the foundation for a wide array of data practices in film.

In the early twentieth century, Paul Otlet, founding figure of information science and deviser of the Universal Decimal Classification, turned to what must be assumed to be cellulose acetate film, or safety film, as a "tough, stable, non-flammable" answer to the problem of preserving and making accessible libraries of books ([1901] 1990). "As early as 1906," Otlet later wrote, "we proposed that the book or documents generally should be given a new form, that of the miniature 'volumen' as follows: each page, element, or combination of pages is photographed directly on a 'frame' or film of the standard motion picture format" ([1925] 1990). The remediation of textual materials on film, Nanna Bonde Thylstrup (2019) has suggested, served both to preserve and to extend the reach of library collections, prefiguring in analog what would later take place in mass digitization. Emphasis in accounts of Otlet's work tends to fall, understandably, on the capacity of film to register textual and pictorial detail photographically, but equally important in Otlet's visionary essays were the mechanical means of transport and how the individual frames came together to "make up a microphotographic reel" ([1901] 1990). Were each image to be on a separate celluloid sheet, the user would have to reload the microfilm or microfiche reader with each page. A reel introduced in informational practice exactly what it introduced in popular cinema: movement. Helmut Müller-Sievers puts this in perspective in seeing "the film camera as a lathe that carves light onto film" (2001, 42), emphasizing the mechanical properties of the apparatus and understanding the film reel to function like any cylinder in a kinematic chain, bringing repeatable mechanical movement to an operation. This repeatable mechanical movement enabled the illusion of life in cinema, and it made possible new access to information on microfilm. To understand the full extent of film's influence on information science, however, requires an understanding of how the storage function on film related to its transmission function, and for that we need to pass through the history of cinema.

The Analog Principle and Photocells

The most information-oriented developments in microfilm concern the soundtrack more than the image track; or rather, they show that the image track is simply one filmic use case centered on lens-based picturing. Inventors from Eugene Lauste to Lee de Forest viewed motion picture film not simply as a means of figural representation but as a translational medium capable of carrying image information that might be converted into sound. The qualities that made film amenable to capturing scenes in photographic detail also made it well-suited for differentiating between elements of analog information. That several standards were developed for sound on film, namely the variable-area and variable-density methods, points to the openness of motion picture film to different informational encodings. The basis of these information tracks had as much to do with the method of reading the light passing through or blocked by the celluloid strip as with the strip itself. That is, the significance of film to data practices extends to the component technologies that it served to advance, the most important of which were photocells.

The first such light-reader, or photosensor, was discovered quite by accident when Willoughby Smith, working on the transatlantic cable in 1872, adopted selenium in hopes of making use of its very high electrical resistance at the English shore end of the line. Smith found that under certain conditions selenium bars showed extraordinary resistance, as high as 1,400 megohms, or as Alexander Graham Bell later put it in perspective, "a resistance equivalent to that which would be offered by a telegraph wire long enough to reach from the earth to the sun!" (1880, 132). But when the bars were exposed to light, the resistance dropped precipitously. Bell for his part would take up this feature, as he explained in a lecture to the Royal Society in May 1878, to devise a way of "hearing a shadow by means of interrupting the action of light upon selenium" (1880, 132). His dream was to develop wireless telephony, a way of sending the voice over great distances using light alone, but he quickly realized that sound could translate into any number of media, so he renamed what he first proposed as the *photophone* the *radiophone* and coined *thermophone* and *actinophone* to describe devices using thermal and actinic rays (Bell 1881, 32, 37). The translatability of sound into electricity, heat, light, and other parts of the electromagnetic spectrum laid bare the principle of analog media, or the significant feature that media could reproduce formal similarity from one medium to another. It was this feature, which, passing through the development of sound on film, would come to form the basis of early electromechanical information systems.

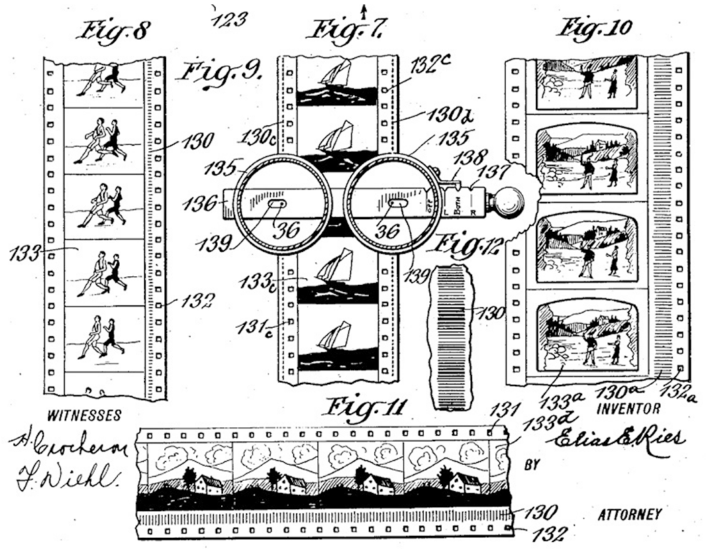
In 1888, Eugene Lauste conceived of a prototype for the optical film soundtrack after reading an article about Bell's photophone. Lauste had been trained in Thomas Edison's laboratory and at the time worked under Edison's lead motion picture engineer, W. K. L. Dickson. First he had the idea to use a band of bromide paper to register sound photographically, but after seeing George Eastman's new commercially available film, which was developed in the same year, he made the switch to celluloid around the time that Dickson was phasing out paper strips in favor of using film for motion pictures. In this way, sound and image alighted on celluloid at the very same moment, even if sound would have to wait another thirty years for a commercially viable system. In 1910, Lauste created the first successful experiment with photographed sound, using a variable density method, a specimen of which was later included in the museum of the Bell Telephone Laboratories (Crawford 1931, 636).

At a time when Edison was decades into his attempt to synchronize moving pictures with the phonograph, as shown in his sound test *Nursery Favorites* (1913), E. E. Ries ([1913] 1926) submitted the first patent application for a variable density method of recording sound on film (fig. 1).[1] Lauste had used a variable area

1 The advantage of sound-on-film over sound-on-disc synchronization is that it virtually guarantees proper synchronization by combining sound and image records on the same medium.

method, in which a "light valve" modified the area where the film was exposed and left a waveform pattern on the soundtrack. The variable density method followed from the experiments of Bell and his associate Charles Sumner Tainter. Instead of varying the area where the light hit the film, it varied the intensity of light, leaving bands of varying brightness on the soundtrack. Significantly, both methods could be reproduced by the same equipment using the same photocells, so that Lauste's method was not entirely lost, returning in the late 1920s as the standard for RCA Photophone in its competition with Fox-Case Movietone's variable density method.[2]

Figure 1: Ries Sound on Film System



Source: Elias E. Ries, US Patent 1,607,480, filed May 21, 1913, and issued November 16, 1926.

That Edison was still trying to synchronize film and sound records on separate media shows a certain poverty of insight, surely due to his own investment in the phonograph.

2 A demonstration of the two recording methods and how they can be run on the same equipment appears in the 1943 ERPI Classroom Film, *Sound Recording and Reproduction (Sound on Film): An Instructional Sound Film*. Along with the Max Fleischer cartoon *Finding His Voice* (1929) and the Vitaphone demonstration *The Voice from the Screen* (1926), this film makes up part of the industry's important effort to naturalize the technology of sound-on-film by explicating its function.

In the annals of sound-on-film, Ries has received little acclaim for his system because, like Lauste before him, he was stuck with the technological dead-end of the selenium cell. He was a lone inventor working on a project that required, when it was finally accomplished, all the might of the professional research laboratories. The complexity of the problem appears in his patent application for "reproducing photographic sound records":

> To reproduce such a record, I employ a method (which is the subject matter of the present application) in which light rays of constant luminosity are projected through an apertured screen similar to the screen employed in making the record, and the record film is moved constantly at a uniform speed in such relation to the aperture, that only an area equal to the area of the aperture will be exposed to the light rays, and the light rays passing through the record film of varying opacity will be projected upon a light sensitive cell or plate, such as selenium. This cell is connected in an electric circuit with a sound reproducing device or telephone, and in accordance with the variations in light rays passing through the record, the light sensitive cell will produce variations in the resistance or cause varying impulses in said circuit to actuate said sound reproducing device or telephone. (Ries 1926, 4)

Ries's sound-on-film system made several important metaphorical leaps: that sound could be transformed into electricity and back into sound (the underlying principle of the telephone); that electricity could be transformed into light and back into an electrical current (the principles of the lightbulb and the selenium cell); and that light could create a record on film capable of being read again by light (the principle of motion pictures). It was an ingenious assembly of metaphors. The trouble was that each metaphor required significant improvements that no single inventor in Ries's time could make alone. As long as he was using a telephone for recording and playback, Ries would never be able to achieve sufficient frequency range and amplification, while the telephone industry had little reason to modify its own technology since it was more than adequate for transmitting the voice intelligibly. Radio and public address would provide early improvements to microphones and loudspeakers in the 1920s, but by the 1930s the film industry would have to develop its own sound technologies, such as Harry F. Olson's invention of the cardioid directional microphone, the shotgun mic, and improved loudspeakers. Having access to only standard light bulbs, Reis would never achieve sufficient luminosity, later supplied by Western Electric bulbs designed specifically for sound-on-film. In 1922, after Lee de Forest bought Ries's patent, de Forest would have to consult with Eastman Kodak about producing a finer-grained film stock to eliminate noise on the soundtrack, an effort that would go on for decades. First and foremost, Ries needed better photocells, the kind of photocells that were going to be developed specifically for reading optical records on film.

In 1918, Lee de Forest began work on what would become Phonofilm, the first commercial application of Ries's patent. Early on, he encountered many of the same limitations that Ries had. After a year of unsuccessful and, it should be noted once again, dangerous efforts given the flammability of nitrate film, de Forest discontinued his "speaking flame" and modified his system to use electrical components, replacing open flames with "light tubes," adding his Audion tube, and testing different photocells (Adams 2012, 219–229). The following year, de Forest contacted Theodore Case about a recent article the latter had published describing the Thalofide cell, a new photoelectric cell growing out of Case's work for the Navy in World War I. Beginning with their correspondence in 1917, de Forest and Case entered a period of professional cooperation, where de Forest brought an overall picture of the sound-on-film idea and Case provided de Forest with invaluable electrical components. Case had begun experimenting with a selenium cell as early as 1911 while still a student at Yale, "with the idea in mind of photographing sound waves," as he relates in a letter to his mother (quoted in Sponable 1947, 284). But he quickly turned away from selenium, adopting a combination of thallium, oxygen, and sulfur that, when used with a vacuum tube, provided an advantageous gain in recovery time, which was "extremely fast," as Case notes in his article, "in marked contrast to selenium" (1920, 290; see also Gomery 2005, 47). Case was not entirely satisfied with his photocell, however, as he notes in a letter to de Forest: "The worst drawback of the Thalofide cell is the hissing noise when exposed to too much light" (as quoted in Adams 2012, 242). And toward the end of his relationship with de Forest, Case improved the device by using potassium. Two *New York Times* headlines registered the significance of Phonofilm in touting its seamless analogical transfer of sound into light: "New Talking Film Photographs Voice" (August 29, 1922); "He 'Photographs' Sounds" (August 17, 1922). But when de Forest failed to mention Case's contributions to Phonofilm in the publicity for its premiere, a dispute arose that led to the dissolution of their relationship. The fruits of their collaboration, however, would continue to grow, and in unexpected ways.

The commercially successful sound-on-film system that Case later developed with Earl Sponable out of this research, the Fox-Case Movietone system, would compete with RCA Photophone and its variable-area method before giving way to Western Electric's optical sound system in 1931. Over the years from de Forest's Phonofilm to the mature sound systems of the 1930s, improvements were made both to photosensors and to film, with simple photocells like the Thalofide cell succumbing to more advanced photomultipliers, such as the RCA 935, and with film stock becoming finer grained. These improvements also facilitated a range of new film data practices in analog computing, microfilm search and retrieval, and mechanical control.

The Transcoding of All Media

In October 1921, de Forest left his home on the Hudson, in New York State, for Berlin where he hoped to get away from the distractions of his ongoing patent disputes, and perhaps to continue his sound-on-film experiments without tipping his hand to other inventors (see Adams 2012, 238–241). Around the same time in Berlin, Hans Richter was working on his seminal abstract film *Rhythmus 21*. It was Richter's first foray into cinema. Spurred on by his collaboration with Viking Eggeling, and inspired by Eggeling's visionary approach to geometrical form, Richter sought to develop a means of universal visual expression. He had been working since the late 1910s with color dynamics and attempts at visual rhythm, carrying on the tradition of color organs and painted music, which Fred Collopy observes in the titles of Richter's paintings from this period: "*Cello*, *Prelude*, *Fugue*, *Rhythmus 23*, and *Orchestration of Color*" (Collopy 2000, 359). *Rhythmus 21* continued these experiments in visual music, now with the addition of motion. As with de Forest, Richter was making sound with light. The difference was that Richter assumed no need to transduce sound into light. The two were instead direct expressions of a more basic "universal form perception." What mattered most of all was the pattern, something that could inhabit any sense domain, translating between sound, light, and movement, as though music rang out through all the spheres.

Richter's works, however, tested only one side of this analogy between light and sound, showing how rhythm and musical form could be expressed in images. The German-born abstract animator and filmmaker Oskar Fischinger, on the other hand, created what Richter had only theorized about. Fischinger's "sounding ornaments," as well as Rudolf Pfenninger's similar synthetic sound experiments (see Levin 2003), used the optical soundtrack to translate images into sounds (fig. 2). Together with his films *Spirals* (1926) and *Allegretto* (1936–1943), which illustrate the idea of sound rhythms transformed into light, Fischinger's ornament sounds give practical application to the notion that form could be universal across media. Writing in 1932, Fischinger explains the "purity" of these "sounding ornaments":

> Between ornament and music persist direct connections, which means that Ornaments are Music. If you look at a strip of film from my experiments with synthetic sound, you will see along one edge a thin stripe of jagged ornamental patterns. These ornaments are drawn music – they are sound: when run through a projector, these graphic sounds broadcast tones or a hitherto unheard of purity, and thus, quite obviously, fantastic possibilities open up for the composition of music in the future. (Fischinger 1932, n.p.)

In a sense, Fischinger took de Forest's technology and cut it in half, doing away with the messy business of capturing images and sounds from "out there" in the world, and simply generating them ex nihilo, in a way that created sounds that never could

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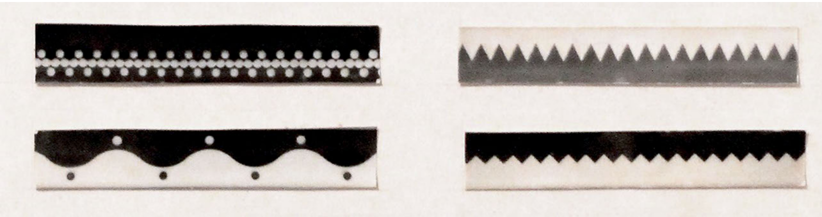
have existed otherwise. If an apparatus could transform light into electricity into sound based on the differential density on a film soundtrack, it could transform any visual shape or density so inscribed on the track. Fischinger was, so to speak, taking what had been a problem for sound designers in Hollywood – the fact that the apparatus would render any "noise" inscribed on the soundtrack, whether scratches or specks or graininess of the film – and turning it into a new form of artistic expression.

Figure 2: Fischinger Drawings



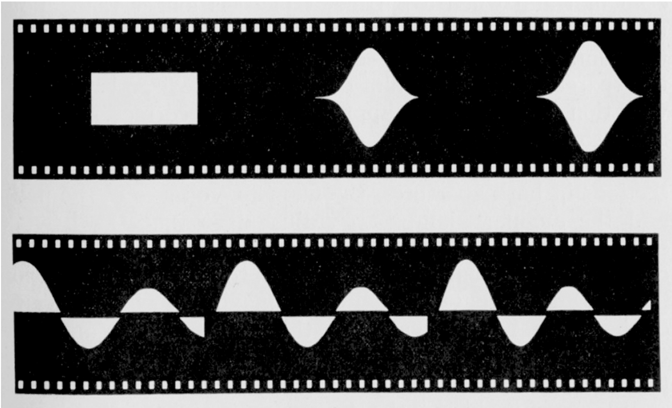
Source: Collection and © Center for Visual Music, Los Angeles.

What is striking about Fischinger's sounding ornaments is that some of the strips are nearly indistinguishable from the control patterns used in an early analog computer, the Cinema Integraph, created by Gordon S. Brown at MIT (fig. 3). The idea of using motion picture film to perform computations more complex than those calculated by Vannevar Bush's Differential Analyzer is said to have occurred to Norbert Wiener while he was enjoying a night at the theater:

> It was the old Copley Theater in Boston, and I'd been thinking very much. You see, I'd been tremendously inspired by Vannevar Bush's work on his various sorts of computing machines, and I thought I'd get a hit in for my own. The optical machine was conceived during the intermission there, and it was taken up and pushed by Bush and by various people whom he lent me, including Dr. Brown. (Brown and Wiener [1955] 1984, 379)

The Cinema Integraph was designed to perform harmonic analysis, which involved more complicated functions than the differential equations performed by Bush's mechanical analyzer. As Wiener summarizes, the problem came in having "numbers distributed over a plane, or over a volume." "If you wanted to solve a problem whose answer was distributed in more dimensions," he recalls, "you had to be able to represent a function in more dimensions" (Brown and Wiener 1955, 380). Wiener's insight was to turn to "the density of a photographic negative, which varies up and down and left and right," utilizing both the vertical and horizontal dimensions of film as variables and in this way capitalizing on the mechanical movement of the reel as well as the photographic space of the frame (Brown and Wiener 1955, 380). As with Fischinger's ornament sounds, the patterns of the Cinema Integraph could be read by an optical sound reader to create noises. It should be no surprise, then, that the optical soundtrack was already being used as a data medium in the 1930s.

Figure 3: Cinema Intergraph



Source: 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), p. 35.

Richard S. Morse, who began his career at Eastman Kodak in 1935 before going on to achieve his greatest fame for being the inventor of frozen orange juice concentrate and founder of the Minute Maid Corporation, sought to bring order to the noise of microfilm's accumulating data trail. In a sense, Morse was doing what Fischinger was doing, creating music out of noise, trying to organize the soundtrack of the modern world. Morse made several contributions to sound-on-film technologies while at Kodak, including an amplification system for home movies, "using a radio receiver to amplify the output of the photoelectric cell of a sound motion picture projector" (Morse 1938, 3), as well as a system for high fidelity recording that used compression during recording and expansion during replay, much the same as an anamorphic lens compresses and expands widescreen images (Morse 1939). He also established important advances in push-pull recording, which used multiple soundtracks side-by-side along the edge of the film to reduce background noise and allow for greater amplification (McLeod and Morse, 1939; see also Hilliard 1938 and Ceccarini 1938). The patent he filed in 1938 for a "Rapid Selector-Calculator" developed out of this work. Its variable density coding system inspired by optical motion picture soundtracks came to be called, in the small circle of microfilm search and retrieval, a data soundtrack (Morse 1942, 1).[3]

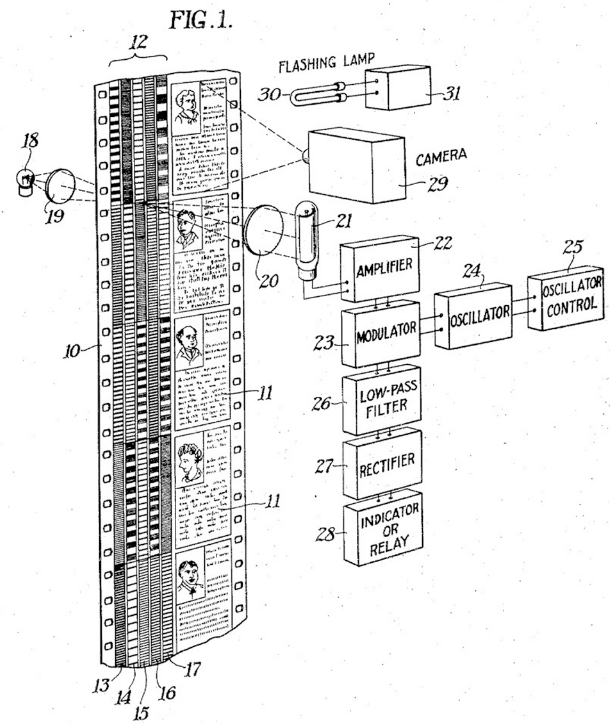
Morse's data soundtracks (fig. 4) promised the automatic sorting, selecting, and calculating of records on microfilm so that records could be found even if the operator did not know their place on the film. The system specialized, in Morse's account, in items such as literature, bank checks, sales records, and personal identification. The device used high-speed photography to capture a duplicate of an "information item" – a single frame on the image track – which made it possible to retrieve multiple items very quickly. Morse gives one example of the machine's "almost innumerable" applications:

> A bureau of criminal investigation is provided with a band carrying either five tracks corresponding to the file numbers of registered criminals or a photographable area showing the number and name of the criminal. Adjacent to these tracks or area is a plurality of characteristics of the criminal such as city, state, or area of activities, type of activity, color of hair, height, approximate year of birth, etc. When a description of a criminal and/or a crime is reported, and corresponding decoding devices (such as oscillators) arranged, the band provides a list of likely suspects in an automatic manner. (Morse 1942, 4)

As Fischinger had done in capturing the fugitive noises of the soundtrack, Morse imagined that data soundtracks captured criminal attributes in an information net. But the device's stated applications made it not simply a benign labor-saving technique. As Morse's description shows, the use of film in data applications sought to expand the power of the carceral state, prefiguring the techniques of predictive policing and racial identification that would characterize the data practices of the later computer revolution (see McIlwain 2019; Benjamin 2019).

3 Morse mentions that the data track might be better termed a "frequency track," but given the analogy with sound-on-film systems the notion of a data soundtrack continued to be the common descriptor in subsequent literature. See, e.g., Burke 1992, 652.

Figure 4: Morse Data Soundtracks



Source: Richard S. Morse, "Rapid Selector-Calculator," US Patent 2,295,000, filed June 23, 1938, and issued September 8, 1942.

Morse's optical technology in a sense brought Hollerith's "punch photograph" full circle once again: the punched card that simulated the optical medium of the photograph returned to the optical medium of film in order to retrieve the data of the punched card. In fact, the punch system of the Hollerith card had already been used in an earlier microfilm search and retrieval system. In 1931, Emanuel Goldberg, inventor of the Kinamo portable camera that Joris Ivens used to film *The Bridge* (1928), presented his Statistical Machine at the Eighth International Congress of Photography in Dresden. The information retrieval system connected with Goldberg's presentation from the night before, when he detailed a new sound-on-film technology developed at Zeiss Ikon. The Statistical Machine was, in biographer Michael Buckland's words, "a revolutionary document search and display system using microfilm for document storage, a photoelectric cell for sensing index codes, and digital circuits for pattern recognition" (Buckland 2006, 155).[4] It was designed to retrieve sales data for business, and used a metadata system very similar to what Morse later used in his Rapid Selector-Calculator.[5] Each record contained a code with certain characteristics, just like Hollerith's punch photographs only now automated on a soundtrack. Goldberg and Morse thus solidified Wiener's intuition that optical computing could control automation, that cinematics could control kinematics (see Stine 2014). Before McLaren's animated sound strips, data soundtracks had already taken up the cybernetic task of animating machines.

At the basis of the experiments of de Forest and Case, Eggeling and Richter, Morse and Goldberg, Fischinger and Pfenninger, Wiener and Brown, is a world conceived in advance as calculable and capable of being translated from one medium to another. That physical materials or forms of energy were expressible in terms of each other was only one small part of this understanding. If the world was conceived in advance as calculable, then all these physical materials and forms of energy – sound, light, electricity, machine movements, etc. – were expressible not only in terms of each other but also universally expressible, by abstraction. Eggeling and Richter understood this from the beginning. Visual music was only one small part of the "universal form expression" they sought to capture through their artistic work. In 1920, the two collaborated on a pamphlet advocating the development of a universal form language "above and beyond all national language frontiers" (as cited in Turvey 2003, 26).[6] The pamphlet expressed a desire that Eggeling had been carrying with him most of his life, and which he promoted in Richter, of creating "a new communication machine" (O'Konor 1971, 7). It would not be long before science would make their dream of a universal language a genuine technical possibility. In 1937, shortly after Fischinger's sounding-ornaments experiments, Alan Turing settled once and for all that these different forms of energy were expressible in a common language with the Universal Turing Machine. The Turing concept would soon make it possible for a single machine to store, process, and transmit all media, whether sound, image, or text.

4 Buckland deserves recognition for restoring Goldberg's place in the history of information science, which was nearly forgotten in the shadow of Vannevar Bush's Memex. The biography also outlines Goldberg's important contributions to photography, cinema, and sound-on-film.

5 Other applications Buckland highlights are check handling and the preparation of telephone subscriber invoices (Buckland 2006, 148).

6 From Hans Richter's retrospective remarks on their collaboration. As Turvey notes, the original text of *Universelle Sprache* ("Universal Language") is probably no longer extant.

A Control Medium for Machine Automation

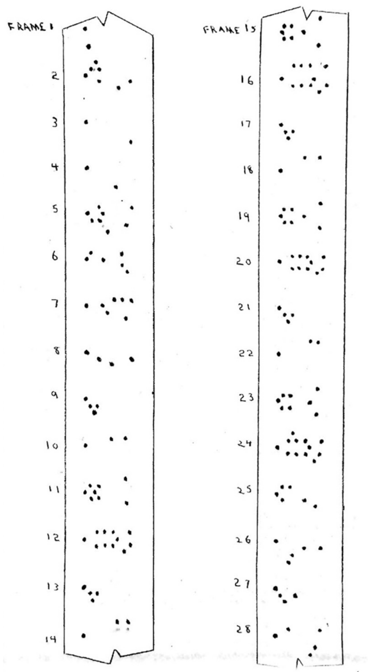
When engineers and inventors set out to develop automatic machine tooling, they turned to the same readily available assemblies of photocells and motion picture film as information scientists had. In his description of the problems facing machine tooling in the 1950s, Frederick W. Cunningham explains: "All of these machines have the disadvantage of requiring that a master piece or, in the automatic screw machine, a set of master cams, be made and installed every time the machine is to be changed from one job to another" (1954, 487). Because of the wear inflicted by the work process, master templates had a short life span, as David F. Noble notes: "Storage of templates, most of which were for a single job or a single part of a job, was costly and required complex inventory and retrieval systems" (1986, 83). To Cunningham's mind, it was necessary to find a control medium for shaping metal parts that would not itself be damaged in the work process. Out the possibilities of magnetic tape, punched cards, and film, he selected film because of its durability, widespread availability, and cost effectiveness.

In a sense, motion pictures had supplied the means of automating interchangeable programs from the beginning. A film projector is capable of showing any film, or in a sense running any program (it is worth recalling that evenings at the movies were historically called "programs"). This ability also made film an especially good medium for controlling machine movements because it was itself motion-controlled by the sprocket holes lining its sides and was intentionally durable for such a purpose. Bazin was right to point out these automatic features of the technology: "For the first time, between the originating object and its reproduction there intervenes only the instrumentality of a nonliving agent" ([1945] 1967, 13). Cinema was early automation. The programs it ran could be projected for people or as clandestine matinees intended only for machines. In this light, Noble's (1995) notion of "progress without people" might be refigured as "cinema without people" because the same technologies that have entertained mass audiences have been just as easily configured to run machines.

Across several fields, researchers realized this advantage of using film to change the program of automatically controlled machines. Cunningham selected 16mm film to solve the problem of cutting non-circular gears, such as those needed for the Army T-41 Rangefinder anti-aircraft gun. Non-circular gears were difficult to produce, even for a skilled machinist. The problem became so great in the aerospace industry that by the end of the 1950s, noncircular and non-rectangular surfaces necessitated automation both in manufacturing and design, a difficulty that would form the thrust of early computer-aided design systems. Cunningham's solution involved an assembly of electronics and photocells set up to read a complicated machining program printed on film, "a continuous stream of data that would dictate the immediate movement of machine elements" (Ashburn 1953, 150). Several other experiments followed similar pursuits. The Swiss firm Contraves A.G. improved on a German machine developed during the war to produce a photo-optical tracer similar to that devised at MIT (see Noble 1995, 83; Hazen, Brown, and Jaeger 1936). Cletus Killian, drawing on his work in developing mechanical computing machines at Remington Rand, similarly experimented with a photo-optical line-following machine, which he called the "Automatic Machinist" (1952, 1). Killian's patent for the machine explicitly lists cellulose acetate and cellulose nitrate film as excellent control tape (1952, 14).[7] Alongside its uses as an analog photographic medium, film also served as punched tape for running machines digitally. Albert Gallatin Thomas, an MIT alumnus who worked with Vannevar Bush in the 1920s, followed Killian's approach to produce a discretely coded system capable of converting digital information, stored on film, into continuous three-axis machine movement (Noble 1986, 87). Extending automatic machining capabilities, F. P. Caruthers developed a system at Thomson Equipment that employed motion picture film as punched tape (fig. 5) in conjunction with a plugboard to control four axes of machine motion (Noble 1986, 92–96; Carr 2014, 271–273). Noble argues in support of Caruthers's method that, unlike MIT's numerical approach, it was designed with machinists in mind, not to replace them. Machining with the system remained a sensory experience rather than an attempt to circumvent the senses: "Through the use of dials which permitted both coarse and fine tuning, the operator could set and adjust feeds and speeds, relying upon accumulated experience with the sights, sounds, and smells of metal cutting" (Noble 1986, 94).

7 The application substituted for an earlier abandoned application dating from May 18, 1943. As Noble notes, however, Killian's work was largely a failure (1986, 87).

Figure 5: Caruthers Punched Film



Source: Caruthers, Felix Porter. 1984. *Automatic Machine Control: A Five Generation History of Numerical Control Systems as Conceived and Developed by Felix Porter Caruthers*. Three Rivers, CA: Caruthers & Associates, Inc., 1984. Smithsonian Institution Archives Center, National Museum of American History, Felix P. Caruthers Papers, 1952–1991, Box 1, Folder 1, n.p.

At the same time, the driving force in photocell innovation was the film industry, where "the principal contemplated application was sound-on-film pickup" (Engstrom 1980, 3–4). Audiences who paid for tickets to the talkies, unwittingly perhaps, drove the demand for photocell applications in a variety of other fields, including machine automation. Although military exploits have often been cited as the very visible hand behind technological growth, they played at best a tangential part in this unfolding where ideological productions screened from view a more pervasive technological pursuit. By the 1940s, photocells were being used for process control in industry, as sensors for the automatic doors at Penn Station in New York, and in two feedback-controlled automatons, Henry Singleton's Moth and Bedbug and Grey Walter's tortoises. As ought to be expected with such feedback systems, it was only a matter of time before developments returned to the entertainment industry with the "total automation of the motion-picture theater" (Boudouris, Gray, and Burlinson 1972, 81).

Conclusion

As this history suggests, the feedback loop between today's cinematic practices and Big Data, such as we see in algorithmic video platforms like Netflix and YouTube, was already in the works in the classical era of film, even if the circuit of their interchange was long and generally imperceptible. Visual media scaled between the two-dimensional world of linear code and the three-dimensional world of machine action, enabling new data practices and the mobilization of these data into new mechanical systems. Film was used to reproduce, most obviously, images, but it also became the support through these images to reproduce any number of other media, such as sound and text. Specifically in terms of its reproduction and search and retrieval of text, film in this way became practical in libraries, hospitals, and police offices, as a means of information processing before digital computing. As Lev Manovich notes, film achieved its greatest effect in computing by obliterating the image, using film not as a pictorial space, but in the case of Konrad Zuse's Z3 computer disregarding the image in the form of a punched-hole code (2002, 20). But as Kittler notes, the binary alternation effectuated by punched holes was part of the medium of film from the beginning in its use of negative–positive photography:

> The consequences of unlimited copying are clear: in a series first of originals, second of negatives, and third of negatives of a negative, photography became a mass medium. For Hegel, the negation of a negation was supposed to be anything but a return to the first position, but mass media are based precisely on this oscillation, as it logically calculated Boolean circuit algebra and made possible nothing less than the computer. (2010, 134)

So it should come as no surprise that the functions of computing were first tested on the medium of film. From Norbert Wiener and Gordon S. Brown's Cinema Integraph to Richard S. Morse's data soundtracks and Emanuel Goldberg's Statistical Machine, in Fredrick Cunningham's noncircular gear shaper and F. P. Caruthers's punched-film machinist, motion picture film was a computing medium that prefigured much of what would be taken up by digital computers. It was a universal medium operating in an era on the cusp of universal computing machines.

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