

The Technical Evolution of Vannevar Bush's Memex

Belinda Barnet <belinda_dot_barnet at gmail_dot_com>, Swinburne University of Technology, Melbourne

Abstract

This article describes the evolution of the design of Vannevar Bush's Memex, tracing its roots in Bush's earlier work with analog computing machines, and his understanding of the technique of associative memory. It argues that Memex was the product of a particular engineering culture, and that the machines that preceded Memex — the Differential Analyzer and the Selector in particular — helped engender this culture, and the discourse of analogue computing itself.

Introduction: Technical Evolution

The key difference [between material cultural evolution and biological evolution] is that biological systems predominantly have “vertical” transmission of genetically ensconced information, meaning parents to offspring... Not so in material cultural systems, where horizontal transfer is rife — and arguably the more important dynamic . (Paleontologist Dr. Niles Eldredge, interview with the author)

Since the early days of Darwinism, analogies have been drawn between biological evolution and the evolution of technical objects and systems. It is obvious that technologies change over time; we can see this in the fact that technologies come in generations; they adapt and adopt characteristics over time, “one suppressing the other as it becomes obsolete” [Guattari 1995, 40]. The technical artefact constitutes a series of objects, a “lineage” or a line. From the middle of the nineteenth century on, writers have been remarking on this basic analogy – and on the alarming rate at which technological change is accelerating. But as Eldredge points out, the analogy can only go so far; technological systems are not like biological systems in a number of important ways, most obviously the fact that they are the products of conscious design. Unlike biological organisms, technical objects are *invented*.

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Inventors learn by experience and experiment, and they learn by watching other machines work in the form of technical prototypes. They also copy and “transfer” ideas and techniques between machines, co-opting innovations at a whim. Technological innovation thus has Lamarckian features, which are forbidden in biology [Ziman 2003, 5]. Inventors can borrow ideas from contemporary technologies, or even from the past. There is no “extinction” in technological evolution: ideas, designs and innovations can be co-opted and transferred both retroactively and laterally. This retroactive and lateral “transfer” of innovations is what distinguishes technical evolution from biological evolution, which is characterised by vertical transfer (parents to offspring). As the American paleontologist Niles Eldredge observed in an interview with the author,

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Makers copy each other, patents affording only fleeting protection. Thus, instead of the neatly bifurcating trees [you see in biological evolution], you find what is best described as “networks”-consisting of an historical signal of what came before what, obscured often to the point of undetectability by this lateral transfer of subsequent ideas . (Niles Eldredge, interview with the author)

Can we say that technical machines have their own genealogies, their own evolutionary dynamic? It is my contention that we can, and I have argued elsewhere that in order to tell the story of a machine, one must trace the path of these transferrals, paying particular attention to technical *prototypes* and to also to *techniques*, or ways of doing things. A good working prototype can send shockwaves throughout an engineering community, and often inspires a host of new

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machines in quick succession. Similarly, an effective technique (for example, storing and retrieving information associatively) can spread between innovations rapidly.

In this article I will be telling the story of particular technical machine – Vannevar Bush's Memex. Memex was an electro-mechanical device designed in the 1930's to provide easy access to information stored associatively on microfilm. It is often hailed as the precursor to hypertext and the web. Linda C. Smith undertook a comprehensive citation context analysis of literary and scientific articles produced after the 1945 publication of Bush's article on the device, "As We May Think" in the *Atlantic Monthly*. She found that there is a conviction, without dissent, that modern hypertext is traceable to this article [Smith 1991, 265]. In each decade since the Memex design was published, commentators have not only lauded it as vision, but also asserted that "technology [has] finally caught up with this vision" [Smith 1991, 278]. For all the excitement, it is important to remember that Memex was never actually built; it exists entirely on paper. Because the design was first published in the summer of 1945, at the end of a war effort and with the birth of computers, theorists have often associated it with the post-War information boom. In fact, Bush had been writing about it since the early 1930s, and the Memex paper went through several different versions.

The social and cultural influence of Bush's inventions are well known, and his political role in the development of the atomic bomb are also well known. What is not so well known is the way the Memex came about as a result of both Bush's earlier work with analog computing machines, and his understanding of the "mechanism" or technique of associative memory. I would like to show that Memex was the product of a particular engineering culture, and that the machines that preceded Memex — the Differential Analyzer and the Selector in particular — helped engender this culture, and the discourse of analogue computing, in the first place. The artefacts of engineering, particularly in the context of a school such as MIT, are themselves productive of new techniques and new engineering paradigms. Prototype technologies create cultures of use around themselves; they create new techniques and new methods that were unthinkable prior to the technology. This was especially so for the Analyzer.

In the context of the early 20th-century engineering school, the analyzers were not only tools but paradigms, and they taught mathematics and method and modeled the character of engineering. [Owens 1991, 6]

Bush transferred technologies directly from the Analyzer and also the Selector into the design of Memex. I will trace this transfer in the first section. He also transferred an electro-mechanical model of human associative memory from the nascent science of cybernetics, which he was exposed to at MIT, into Memex. We will explore this in the second section. In both cases, we will be paying particular attention to the structure and architecture of the technologies concerned.

The idea that technical artefacts evolve in this way, by the transfer of both technical innovations (for example, microfilm) and techniques (for example, association as a storage technique), was popularised by French technology historian Bertrand Gille. I will be mobilising Gille's theories here as I trace the evolution of the Memex design. We will begin with Bush's first analogue computer, the Differential Analyzer.

The Analyzer and the Selector

The Differential Analyzer was a giant, electromechanical gear and shaft machine which was put to work during the war calculating artillery ranging tables and the profiles of radar antennas. In the late 1930s and early 1940s, it was "the most important computer in existence in the US" [Owens 1991, 3]. Before this time, the word "computer" had meant a large group of mostly female humans performing equations by hand or on limited mechanical calculators. The Analyzer evaluated and solved these equations by mechanical integration. It created a small revolution at MIT. Many of the people who worked on the machine (e.g. Harold Hazen, Gordon Brown, Claude Shannon) later made contributions to feedback control, information theory, and computing [Mindell 2000]. The machine was a huge success which brought prestige and a flood of federal money to MIT and Bush.

However, by the spring of 1950, the Analyzer was gathering dust in a storeroom — the project had died. Why did it fail? Why did the world's most important analogue computer end up in a back room within five years? This story will itself be

related to why Memex was never built; research into analogue computing technology in the interwar years, the Analyzer in particular, contributed to the rise of digital computing. It demonstrated that *machines could automate the calculus*, that machines could automate human cognitive techniques.

The decade between the Great War and the Depression was a bull market for engineering [Owens 1991, 29]. Enrolment in the MIT Electrical Engineering Department almost doubled in this period, and the decade witnessed the rapid expansion of graduate programs. The interwar years found corporate and philanthropic donors more willing to fund research and development within engineering departments, and there were serious problems to be worked on generated by communications failures during the Great War. In particular, engineers were trying to predict the operating characteristics of power-transmission lines, long-distance telephone lines, commercial radio and other communications technologies (Beniger calls this the “early” period of the Control Revolution [Beniger 1986, 19]). MIT’s Engineering Department undertook a major assault on the mathematical study of long-distance lines.

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Of particular interest to the engineers was the Carson equation for transmission lines. This was a simple equation, but it required intensive mathematical integration to solve.

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Early in 1925 Bush suggested to his Graduate Student Herbert Stewart that he devise a machine to facilitate the recording of the areas needed for the Carson equation ... [and a colleague] suggested that Stewart interpret the equation electrically rather than mechanically. [Owens 1991, 7]

So the equation was transferred to an electro-mechanical device: the Product Intergraph. Many of the early analogue computers that followed Bush’s machines were designed to automate existing mathematical equations. This particular machine physically mirrored the equation itself. It incorporated the use of a mechanical “integrator” to record the areas under the curves (and thus the integrals), which was

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... in essence a variable-speed gear, and took the form of a rotating horizontal disk on which a small knife-edged wheel rested. The wheel was driven by friction, and the gear ratio was altered by varying the distance of the wheel from the axis of rotation of the disk. [Hartree 2000]

A second version of this machine incorporated two wheel-and-disc integrators, and it was a great success. Bush observed the success of the machine, and particularly the later incorporation of the two wheel-and-disc integrators, and decided to make a larger one, with more integrators and a more general application than the Carson equation. By the fall of 1928, Bush had secured funds from MIT to build a new machine. He called it the Differential Analyzer, after an earlier device proposed by Lord Kelvin which might externalise the calculus and “mechanically integrate” its solution [Hartree 2000].

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As Bertrand Gille observes, a large part of technical invention occurs by transfer, whereby the functioning of a structure is analogically transposed onto another structure, or the same structure is generalised outwards [Gille 1986, 40]. This is what happened with the Analyzer — Bush saw the outline of such a machine in the Product Intergraph. The Differential Analyzer was rapidly assembled in 1930, and part of the reason it was so quickly done was that it incorporated a number of existing engineering developments, particularly a device called a torque amplifier, designed by Niemann [Shurkin 1996, 97]. But the disk integrator, a technology borrowed from the Product Intergraph, was the heart of the Analyzer and the means by which it performed its calculations. When combined with the torque amplifier, the Analyzer was “essentially an elegant, dynamical, mechanical model of the differential equation” [Owens 1991, 14]. Although Lord Kelvin had suggested such a machine previously, Bush was the first to build it on such a large scale, and it happened at a time when there was a general and urgent need for such precision. It created a small revolution at MIT.

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In engineering science, there is an emphasis on working prototypes or “deliverables”. As Professor of Computer Science Andries van Dam put it in an interview with the author, when engineers talk about work, they mean “work in the sense of machines, software, algorithms, things that are *concrete*” [Van Dam 1999]. This emphasis on concrete work was the same in Bush’s time. Bush had delivered something which had been previously only been dreamed about; this meant that others could come to the laboratory and learn by observing the machine, by watching it integrate, by imagining other applications. A working prototype is different to a dream or white paper — it actually creates its own

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milieu, it *teaches those who use it* about the possibilities it contains and its material technical limits. Bush himself recognised this, and believed that those who used the machine acquired what he called a “mechanical calculus”, an internalised knowledge of the machine. When the army wanted to build their own machine at the Aberdeen Proving Ground, he sent them a mechanic who had helped construct the Analyzer. The army wanted to pay the man machinist’s wages; Bush insisted he be hired as a consultant [Owens 1991, 24].

I never consciously taught this man any part of the subject of differential equations; but in building that machine, managing it, he learned what differential equations were himself ... [it] was interesting to discuss the subject with him because he had learned the calculus in mechanical terms — a strange approach, and yet he understood it. That is, he did not understand it in any formal sense, he understood the fundamentals; he had it under his skin. (Bush 1970, 262 cited in Owens 1991, 24)

Watching the Analyzer work did more than just teach people about the calculus. It also taught people about what might be possible for mechanical calculation — for *analogue computers*. Several laboratories asked for plans, and duplicates were set up at the US Army’s Ballistic Research Laboratory, in Maryland, and at the Moore School of Electrical Engineering at the University of Pennsylvania [Shurkin 1996, 99]. The machine assembled at the Moore school was much larger than the MIT machine, and the engineers had the advantage of being able to learn from the mistakes and limits of the MIT machine [Shurkin 1996, 102]. Bush also created several more Analyzers, and in 1936 the Rockefeller Foundation awarded MIT \$85,000 to build the Rockefeller Differential Analyzer [Owens 1991, 17]. This provided more opportunities for graduate research, and brought prestige and a flood of funding to MIT.

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But what is interesting about the Rockefeller Differential Analyzer is what remained the same. Electrically or not, automatically or not, the newest edition of Bush’s analyzer still interpreted mathematics in terms of mechanical rotations, still depended on expertly machined wheel-and-disc integrators, and still drew its answers as curves. [Owens 1991, 32]

Its technical processes remained the same. It was an analogue device, and it literally turned around a central analogy: the rotation of the wheel shall be the area under the graph (and thus the integrals). The Analyzer directly mirrored the task at hand; there was a mathematical transparency to it which at once held observers captive and promoted, in its very workings, the “language of early 20th-century engineering” [Owens 1991, 32]. There were visitors to the lab, and military and corporate representatives that would watch the machine turn its motions. It seemed the adumbration of future technology. Harold Hazen, the head of the Electrical Engineering Department in 1940 predicted the Analyzer would “mark the start of a new era in mechanized calculus” (Hazen 1940, 101 cited in Owens 1991, 4). Analogue technology held much promise, especially for military computation — and the Analyzer had created a new era. The entire direction and culture of the MIT lab changed around this machine to woo sponsors [Nyce 1991, 39]. In the late 1930s the department became the Center of Analysis for Calculating Machines.

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Many of the Analyzers built in the 1930s were built using military funds. The creation of the first Analyzer, and Bush’s *promotion* of it as a calculation device for ballistic analysis, had created a link between the military and engineering science at MIT which was to endure for over thirty years. Manuel De Landa (1994) puts great emphasis in his work on this connection, particularly as it was further developed during WWII. As he puts it, Bush created a “bridge” between the engineers and the military, he “connected scientists to the blueprints of generals and admirals” [De Landa 1994, 119], and this relationship would grow infinitely stronger during WWII. Institutions that had previously occupied exclusive ground such as physics and military intelligence had begun communicating in the late 1930s, “communities often suspicious of one another: the inventors and the scientists on the one side and the warriors on the other” [De Landa 1994, 36].

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This paper has been arguing that the Analyzer *qua* technical artefact accomplished something equally important: as a prototype, it demonstrated the potential of analogue computing technology for analysis, and engendered an engineering culture around itself that took the machine to be a teacher. This is why, even after the obsolescence of the Analyzer, it was kept around at MIT for its educational value [Owens 1991, 23]. It demonstrated that machines could automate the

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calculus, and that machines could mirror human tasks in an elegant fashion: something which required proof in steel and brass. The “aura” generated by the Analyzer as prototype was not lost on the military.

In 1935, the Navy came to Bush for advice on machines to crack coding devices like the new Japanese cipher machines [Burke 1991, 147]. They wanted a long-term project that would give the United States the most technically advanced cryptanalytic capabilities in the world, a super-fast machine to count the coincidences of letters in two messages or copies of a single message. Bush assembled a research team for this project that included Claude Shannon, one of the early information theorists and a significant part of the emerging cybernetics community [Nyce 1991, 40].

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There were three new technologies emerging at the time which handled information: photoelectricity, microfilm and digital electronics.

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All three were just emerging, but, unlike the fragile magnetic recording his students were exploring, they appeared to be ready to use in calculation machines. Microfilm would provide ultra-fast input and inexpensive mass-memory, photoelectricity would allow high-speed sensing and reproduction, and digital electronics would allow astonishingly fast and inexpensive control and calculation. [Burke 1991, 147]

Bush transferred these three technologies to the new design. This decision was not pure genius on his part; they were perfect analogues for a popular conception of how the brain worked at the time. The scientific community at MIT were developing a pronounced interest in man-machine analogues, and although Claude Shannon had not yet published his information theory it was already being formulated, and there was much discussion around MIT about how the brain might process information in the manner of an analogue machine. Bush thought and designed in terms of analogies between brain and machine, electricity and information. This was also the central research agenda of Norbert Weiner and Warren McCulloch, both at MIT, who were at the time “working on parallels they saw between neural structure and process and computation” ([Nyce 1991, 63]; see also [Hayles 1999]). To Bush and Shannon, microfilm and photoelectricity seemed perfect analogues to the *electrical relay circuits and neural substrates of the human brain* and their capacities for managing information.

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Bush called this machine the Comparator — it was to do the hard work of comparing text and letters for the humble human mind. Like the analytic machines before it and all other technical machines being built at the time, this was an analogue device; it directly mirrored the task at hand on a mechanical level. In this case, it directly mirrored the operations of “searching” and “associating” on a mechanical level, and, Bush believed, it mirrored the operations of the human mind and memory. Bush began the project in mid-1937, while he was working on the Rockefeller Analyzer, and agreed to deliver a code-cracking device based on these technologies by the next summer [Burke 1991, 147].

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But immediately, there were problems in its development. Technical objects often depart from their fabricating intention; sometimes because they are *used* differently to what they were invented for, and sometimes because the *technology itself* breaks down. Microfilm did not behave the way Bush wanted it to. As a material it was very fragile, sensitive to light and heat, and tore easily; it had too many “bugs”. It was decided to use paper tape with minute holes, although paper was only one-twentieth as effective as microfilm [Burke 1991, 147]. There were subsequent problems with this technology — paper itself is flimsy, and it refused to work well for long periods intact. There were also problems shifting the optical reader between the two message tapes. Bush was working on the Analyzer at the time, and didn’t have the resources to fix these components effectively. By the time the Comparator was turned over to the Navy, it was very unreliable, and didn’t even start up when it was unpacked in Washington [Burke 1991, 148]. The Comparator prototype ended up gathering dust in a Navy storeroom, but much of the architecture was transferred to subsequent designs.

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By this time, Bush had also started work on the Memex design. He transferred much of the architecture from the Comparator, including photoelectrical components, an optical reader and microfilm. In tune with the times, Bush had developed a fascination for microfilm in particular as an information storage technology, and although it had failed to work properly in the Comparator, he wanted to try it again. It would appear as the central technology in the Rapid Selector and also in the Memex design.

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In the 1930s, many believed that microfilm would make information universally accessible and thus spark an intellectual revolution ([Farkas-Conn 1990, 16–22], cited in [Nyce 1991, 49]). Like many others, he had been enthusiastically exploring its potential in his writing [Bush 1991a], [Bush 1939] as well as the Comparator; the Encyclopaedia Britannica “could be reduced to the volume of a matchbox. A library of a million volumes could be compressed into one end of a desk” he wrote [Bush 1991c, 93]. In 1938, H.G. Wells even wrote about a “Permanent World Encyclopaedia” or Planetary Memory that would carry all the world’s knowledge. It was based on microfilm.

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By means of microfilm, the rarest and most intricate documents and articles can be studied now at first hand, simultaneously in a score of projection rooms. There is no practical obstacle whatever now to the creation of an efficient index to all human knowledge, ideas, achievements, to the creation, that is, of a complete planetary memory for all mankind. [Wells 1938], cited in [Nyce 1991, 50]

Microfilm promised *faithful reproduction* as well as miniaturisation. It was state-of-the-art technology, and not only did it seem the perfect analogy for material stored in the neural substrate of the human brain, it seemed to have a certain permanence the brain lacked. Bush put together a proposal for a new microfilm selection device, based on the architecture of the Comparator, in 1937. Its stated research agenda and intention was

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- Construction of experimental equipment to test the feasibility of a device which would search reels of coded microfilm at high speed and which would copy selected frames on the fly, for printout and use.
- Investigation of the practical utility of such equipment by experimental use in a library.
- Further development aimed at exploration of the possibilities for introducing such equipment into libraries generally.

(Bagg and Stevens 1961, cited in Nyce 1991, 41)

Corporate funding was secured for the Selector by pitching it as a microfilm machine to modernise the library [Nyce 1991, 41]. Abstracts of documents were to be captured by this new technology and reduced in size by a factor of 25. As with the Comparator, long rolls of this film were to be spun past a photoelectric sensing station. If a match occurred between the code submitted by a researcher and the abstract codes attached to this film [Burke 1991, 151], the researcher was presented with the article itself and any articles previously associated with it. This was to be used in a public library, and unlike his nascent idea concerning Memex, he wanted to tailor it to commercial and government record-keeping markets.

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Bush considered the Selector as a step towards the mechanised control of scientific information, which was of immediate concern to him as a scientist. According to him, the fate of the nation depended on the effective management of these ideas lest they be lost in a brewing data storm. Progress in information management was not only inevitable, it was “essential if the nation is to be strong” [Bush 1970, 149]. This was his fabricating intention. He had been looking for support for a Memex-like device for years, but after the failure of the Comparator, finding funds for this “library of the future” was very hard [Burke 1991, 149]. Then in 1938, Bush received funding from the National Cash Register Company and the Eastman Kodak Company for the development of an apparatus for rapid selection, and he began to transfer the architecture from the Comparator across to the new design.

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But as Burke writes, the technology of microfilm and the tape-scanners began to impose their technical limitations;

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[a]lmost as soon as it was begun, the Selector project drifted away from its original purpose and began to show some telling weaknesses ... Bush planned to spin long rolls of 35mm film containing the codes and abstracts past a photoelectric sensing station so fast, at speeds of six feet per second, that 60,000 items could be tested in one minute. This was at least one hundred-fifty times faster than the mechanical tabulator. [Burke 1991, 150]

The Selector’s scanning station was similar to that used in the Comparator. But in the Selector, the card containing the code of interest to the researcher would be stationary. Bush and others associated with the project “were so entranced

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with the speed of microfilm tape that little attention was paid to coding schemes” [Burke 1991, 151], and when Bush handed the project over to three of his researchers, John Howard, Lawrence Steinhardt and John Coombs, it was floundering. After three more years of intensive research and experimentation with microfilm, Howard had to inform the Navy that the machine would not work [Burke 1991, 149]. Microfilm, claimed Howard, would deform at such speeds and could not be aligned so that coincidences could be identified. Microfilm warps under heat, and it cannot take great strain or tension without distorting.

Solutions were suggested (among them slowing down the machine, and checking abstracts before they were used) [Burke 1991, 154], but none of these were particularly effective, and a working machine wasn't ready until the fall of 1943. At one stage, because of an emergency problem with Japanese codes, it was rushed to Washington — but because it was so unreliable, it went straight back into storage. So many parts were pulled out that the machine was never again operable [Burke 1991, 158]. In 1998, the Selector made Bruce Sterling's Dead Media List, consigned forever to a lineage of failed technologies. Microfilm did not behave the way Bush and his team wanted it to. It had its own material limits, and these didn't support speed of access.

In the evolution of any machine, there will be internal limits generated by the behaviour of the technology itself; Gille calls these “endogenous” limits [Gille 1986]. Endogenous limits are encountered only in practice — they effect the actual *implementation* of an idea. In engineering practice, these failures can teach inventors about the material potentials of the technology as well. The Memex design altered significantly through the 1950s; Bush had learned from the technical failures he was encountering. But most noticeable of all, Bush stopped talking about microfilm and about hardware.

By the 1960's the project and machine failures associated with the Selector, it seems, made it difficult for Bush to think about Memex in concrete terms. [Burke 1991, 161]

The Analyzer, meanwhile, was being used extensively during WWII for ballistic analysis and calculation. Wartime security prevented its public announcement until 1945, when it was hailed by the press as a great “electromechanical brain” ready to advance science by freeing it from the pick-and-shovel work of mathematics (*Life* magazine, cited by Owens 1991, 3). It had created an entire culture around itself. But by the mid-1940s, the enthusiasm had died down; the machine seemed to pale beside the new generation of digital machines. The war had also released an unprecedented sum of money into MIT and spawned numerous other new laboratories. It “ushered in a variety of new computation tasks, in the field of large-volume data analysis and real-time operation, which were beyond the capacity of the Rockefeller instrument” [Owens 1991, 5]. By 1950, the Analyzer had become an antique, conferred to back-room storage.

What happened? The reasons The Analyzer fell into disuse were quite different to the Selector; its limits were *exogenous* to the technical machine itself. They were related to a fundamental paradigm shift within computing, from analogue to digital. According to Gille, the birth of a new technical system is rapid and unforeseeable; new technical systems are born with the limits of the old technical systems, and the period of change is brutal, fast and discontinuous. In 1950, Warren Weaver and Samuel Caldwell met to discuss the Analyzer and the analogue computing program it had inspired at MIT, a large program which had become out of date more swiftly than anyone could have imagined. They noted that in 1936, no one could have expected that within ten years the whole field of “computer science” would so quickly overtake Bush's project (Weaver and Caldwell, cited in [Owens 1991, 4]). Bush, and the department at MIT which had formed itself around the Analyzer and analogue computing, had been left behind.

I do not have the space here to trace the evolution of digital computing at this time in the US and the UK — excellent accounts have already been written by [Beniger 1986], [Shurkin 1996], [Ceruzzi 1998], [Edwards 1997] and [De Landa 1994] to name a few. All we need to realise at this point is that the period between 1945 and 1967, the years between the publication of the first and the final versions of the Memex essays respectively, had witnessed enormous change. The period saw not only the rise of digital computing, beginning with the construction of a few machines in the post-war period and developing into widespread mainframe processing for American business, it also saw the explosive growth of commercial television [Spar 2001, 194], and the beginnings of satellite broadcasting [Spar 2001, 197]. As Beniger sees it, the world had discovered information as a means of control [Beniger 1986, vii].

It is important to understand, however, that Bush was not a part of this revolution. He had not been trained in digital computation or information theory, and knew little about the emerging field of digital computing. He was immersed in a different technical system: analogue machines interpreted mathematics in terms of mechanical rotations, storage and memory as a physical “holding” of information, and drew their answers as curves. They directly mirrored the operations of the calculus. Warren Weaver expressed his regret over the passing of analogue machines and the Analyzer in a letter to the director of MIT's Center of Analysis: 37

It seems rather a pity not to have around such a place as MIT a really impressive Analogue computer; for there is a vividness and directness of meaning of the electrical and mechanical processes involved ... which can hardly fail, I would think, to have a very considerable educational value. (Weaver, cited in Owens 1991, 5)

The passing away of analogue computing was the passing away of an ethos: machines as mirrors of mathematical tasks. But Bush and Memex remained in the analogue era; in all versions of the Memex essay, his goal remained the same: “he sought to develop a machine that mirrored and recorded the patterns of the human brain” [Nyce 1991, 123], even when this era of direct reflection and analogy in mechanical workings had passed. 38

Technological evolution moves faster than our ability to adjust to its changes. More precisely, it moves faster than the *techniques* that it engenders and the culture it forms around itself. Bush expressed some regret over this speed of passage near the end of his life, or, perhaps, sadness over the obsolescence of his own engineering techniques. 39

The trend had turned in the direction of digital machines, a whole new generation had taken hold. If I mixed with it, I could not possibly catch up with new techniques, and I did not intend to look foolish. [Bush 1970, 208]

Human Associative Memory and Biological-Mechanical Analogues

There is another revolution under way, and it is far more important and significant than [the industrial revolution]. It might be called the mental revolution. [Bush 1991b, 165]

We now turn to Bush's fascination with, and exposure to, new models of human associative memory gaining current in his time. Bush thought and designed his machines in terms of biological-mechanical analogues; he sought a symbiosis between “natural” human thought and his thinking machines. 40

As Nyce and Kahn observe, in all versions of the Memex essay (1939, 1945, 1967), Bush begins his thesis by explaining the dire problem we face in confronting the great mass of the human record, criticising the way information was then organised [Nyce 1991, 56]. He then goes on to explain the reason why this form of organisation doesn't work: it is *artificial*. Information should be organised by association — this is how the mind works. If we fashion our information systems after this mechanism, they will be truly revolutionary. 41

Our ineptitude at getting at the record is largely caused by the artificiality of systems of indexing. When data of any sort are placed in storage, they are filed alphabetically or numerically, and information is found (when it is) by tracing it down from subclass to subclass. It can only be found in one place, unless duplicates are used; one has to have rules as to which path will locate it, and the rules are cumbersome. Having found one item, moreover, one has to emerge from the system and re-enter on a new path.

The human mind does not work that way. It operates by association. With one item in grasp, it snaps instantly to the next that is suggested by the association of thoughts, in accordance with some intricate web of trails carried by the cells of the brain. (Bush 1939, 1945, 1967)

These paragraphs were important enough that they appeared verbatim in all versions of the Memex essay — 1939, 1945 and 1967 [Nyce 1991, 57]. No other block of text remained unchanged over time; the technologies used to implement the mechanism changed, Memex grew “intelligent”, the other machines (the Cyclops Camera, the Vocoder) disappeared. These paragraphs, however, remain a constant. Given this fact, Nelson's assertion that the major concern 42

of the essay was to point out the artificiality of systems of indexing, and to propose the associative mechanism as a solution for this [Nelson 1991, 248] seems reasonable. Nelson also maintains that these central precepts of the design have been “ignored” by commentators [Nelson 1991, 245]. I would contend that they have not been *ignored*; fragments of these paragraphs are often cited, particularly relating to association. What is ignored is the relationship between these two paragraphs — the central *contrast* he makes between conventional methods of indexing and the mental associations Memex was to support [Nyce 1991, 57]. Association was more “natural” than other forms of indexing — more human. This is why it was revolutionary.

Which is interesting, because Bush’s model of mental association was itself technological; the mind “snapped” between allied items, an unconscious movement directed by the trails themselves, trails “of brain or of machine” [Bush 1970, 191]. Association was a technique that worked independently of its substrate, and there was no spirit attached to this machine: “my brain runs rapidly — so rapidly I do not fully recognize that the process is going on” [Bush 1970, 191]. The “speed of action” in the retrieval process from neuron to neuron [Bush 1970, 102] resulted from a “mechanical switching” (this term was omitted from the *Life* reprint of *Memex II*, Bush 1970, 100), and the items that this mechanical process resurrected were also stored in the manner of magnetic or drum memory: the brain is like a substrate for “memories, sheets of data” [Bush 1970, 191].

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Bush’s model of human associative memory was an electro-mechanical one — a model that was being keenly developed by Claude Shannon, Warren McCulloch and Walter Pitts at MIT, and would result in the McCulloch-Pitts neuron [Hayles 1999, 65]. The MIT model of the human neuronal circuit constructed the human in terms of the machine, and later articulated it more thoroughly in terms of computer switching. In a 1944 letter to Weeks, for example, Bush argued that “a great deal of our brain cell activity is closely parallel to the operation of relay circuits”, and that “one can explore this parallelism...almost indefinitely” (November 6, 1944; cited in Nyce and Kahn 1991, 62).

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In the 1930s and 1940s, the popular scientific conception of mind and memory was a mechanical one. An object or experience was perceived, transferred to the memory-library’s receiving station, and then “installed in the memory-library for all future reference” [Dennett 1993, 121]. It had been known since the early 1900s that the brain comprised a tangle of neuronal groups that were interconnected in the manner of a network, and recent research had shown that these communicated and “stored” information across the neural substrate, in some instances creating further connections, via minute electrical “vibrations”. According to Bush, memories that were not accessed regularly suffered from this neglect by the conscious mind and were prone to fade. The pathways of the brain, its indexing system, needed constant electrical stimulation to remain strong. This was the problem with the neural network: “items are not fully permanent, memory is transitory” [Bush 1991c, 102]. The major technical problem with human memory was its tendency toward decay.

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According to Manuel De Landa, there was also a widespread faith in biological-mechanical analogues at the time as models to boost human functions. The military had been attempting to develop technologies which mimicked and subsequently replaced human faculties for many years [De Landa 1994, 127] and this was especially heightened in the years before, during and immediately following the war. At MIT in particular, there was a tendency to take “the image of the machine as the basis for the understanding of man” and vice versa, writes Harold Hatt in his book on Cybernetics [Hatt 1968, 28]. The idea that Man and his environment are mechanical systems which can be studied, improved, mimicked and controlled was growing, and later gave way to disciplines such as cognitive science and artificial intelligence. Wiener and McCulloch “looked for and worked from parallels they saw between neural structure and process and computation” [Nyce 1991, 63], a model which changed with the onset of digital computing to include on/off states. The motor should first of all model itself on man, and eventually augment or replace him.

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Bush explicitly worked with such methodologies — in fact, “he not only thought with and in these terms, he built technological projects with them” [Nyce 1991, 62]. The first step was understanding the mechanical “process” or nature of thought itself; the second step was transferring this process to a machine. So there is a double movement within Bush’s work, the location of a “natural” human process within thought, a process which is already machine-like, and the subsequent refinement and modelling of a particular technology on that process. Technology should depart from nature, it should depart from an extant human process: this saves us so much work. If this is done properly, “[it] should be

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possible to beat the mind decisively in the permanence and clarity of the items resurrected from storage” [Bush 1970, 191].

So Memex was first and foremost an extension of human memory and the associative movements that the mind makes through information: a mechanical analogue to an already mechanical model of memory. Bush transferred this idea into information management; Memex was distinct from traditional forms of indexing not so much in its mechanism or content, but in the way it organised information based on association. The design did not spring from the ether, however; the first Memex design incorporates the technical architecture of the Rapid Selector and the methodology of the Analyzer — the machines Bush was assembling at the time.

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The Design of Memex

Bush’s autobiography, *Pieces of the Action*, and also his essay “Memex Revisited” tell us that he started work on the design in the early 1930s [Bush 1991d, 197]; [Bush 1970, 130]. Nyce and Kahn also note that he sent a letter to Warren Weaver describing a Memex-like device in 1937 [Nyce 1991, 43]. The first extensive description of it in print, however, is found in the 1939 essay “Mechanization and the Record” [Bush 1939]. The description in this essay employs the same *methodology* Bush had used to design the Analyzer: combine existing lower-level technologies into a single machine with a higher function that automates the “pick-and-shovel” work of the human mind [Owens 1991, 3].

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Nyce and Kahn maintain that Bush took this methodology from the Rapid Selector [Nyce 1991, 54]: this paper has argued that it was first deployed in the Analyzer. The Analyzer was the first working analogue computer at MIT, and it was also the first large-scale engineering project to combine lower-level, extant technologies and automate what was previously a human cognitive technique: the integral calculus. It incorporated two lower-level analogue technologies to accomplish this task: the wheel-and-disk integrator and the torque amplifier, as we have explored. Surrounded by computers and personal organisers, the idea of automating intellectual processes seems obvious to us now — but in the early 1930s the idea of automating what was essentially a *function within thought* was radical. Bush needed to convince people that it was worthwhile. In 1939, Bush wrote:

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The future means of implementing thought are ... fully as worthy of attention by one who wonders what comes next as are new ways of extracting natural resources, or of killing men. [Bush 1939]

The idea of creating a machine to aid the mind did not belong to Bush, nor did the technique of integral calculus (or association for that matter); he was, however, arguably the first person to externalise this technology on a grand scale. Observing the success of the Analyzer *qua* technical artefact, the method proved successful. Design on the first microfilm selection device, the Comparator, started in 1935. This, too, was a machine to aid the mind: it was essentially a counting machine, to tally the coincidence of letters in two messages or copies of a single message. It externalised the “drudge” work of cryptography, and Bush “rightly saw it as the first electronic data-processing machine” [Burke 1991, 147]. The Rapid Selector which followed it incorporated much of the same architecture, as we have explored — and this architecture was in turn transferred to Memex.

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The Memex-like machine proposed in Bush’s 1937 memo to Weaver shows just how much [the Selector] and the Memex have in common. In the rapid selector, low-level mechanisms for transporting 35mm film, photo-sensors to detect dot patterns, and precise timing mechanisms combined to support the high-order task of information selection. In Memex, photo-optic selection devices, keyboard controls, and dry photography would be combined ... to support the process of the human mind. [Nyce 1991, 44]

The difference, of course, was that Bush’s proposed Memex would access information stored on microfilm by *association*, not numerical indexing. He had incorporated another technique (a technique which was itself quite popular among the nascent cybernetics community at MIT, and already articulated mind and machine together). By describing an imaginary machine, Bush had “selected from the existing technologies of the time and made a case for how they should develop in the future” [Nyce 1991, 45]. But this forecasting did not come from some genetically inherited genius — it was an acquired skill: Bush was close to the machine.

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As Professor of Engineering at MIT (and after 1939, President of the Carnegie Institute in Washington), Bush was in a unique position — he had access to a pool of ideas, techniques and technologies which the general public, and engineers at other smaller schools, did not have access to. Bush had a more “global” view of the combinatory possibilities and the technological lineage. Bush himself admitted this; in fact, he believed that engineers and scientists were the only people who could or *should* predict the future of technology — anyone else had no idea. In “The Inscrutable Thirties”, an essay he published in 1933, he tells us that politicians and the general public simply can’t understand technology, they have “so little true discrimination” [Bush 1991a, 77] and are “wont to visualize scientific triumphs as *faits accomplis* ” before they are even ready, “even as they are being hatched in the laboratory” [Bush 1991a, 75]. Bush believed that the prediction and control of the future of technology should be left to engineers; only they can “distinguish the *possible* from the virtually *impossible* ” [Nyce 1991, 49], only they can read the future from technical objects.

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Memex was a future technology. It was originally proposed as a desk at which the user could sit, equipped with two “slanting translucent screens” upon which material would be projected for “convenient reading” [Bush 1991c, 102]. There was a keyboard to the right of these screens, and a “set of buttons and levers” which the user could depress to search the information using an electrically-powered optical recognition system. If the user wished to consult a certain piece of information, “he [tapped] its code on the keyboard, and the title page of the book promptly appear[ed]” [Bush 1991c, 103]. The images were stored on microfilm inside the desk, “and the matter of bulk [was] well taken care of” by this technology — “only a small part of the interior is devoted to storage, the rest to mechanism” [Bush 1991c, 102]. It looked like an “ordinary” desk, except it had screens and a keyboard attached to it. To add new information to the microfilm file, a photographic copying plate was also provided on the desk, but most of the Memex contents would be “purchased on microfilm ready for insertion” [Bush 1991c, 102]. The user could classify material as it came in front of him using a teleautograph stylus, and register links between different pieces of information using this stylus. This was a piece of furniture from the future, to live in the home of a scientist or an engineer, to be used for research and information management.

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The 1945 Memex design also introduced the concept of “trails”, a concept derived from work in neuronal storage-retrieval networks at the time, which was a method of connecting information by linking units together in a networked manner, similar to hypertext paths. The process of making trails was called “trailblazing”, and was based on a mechanical provision “whereby any item may be caused at will to select immediately and automatically another” [Bush 1991c, 107], just as though these items were being “gathered together from widely separated sources and bound together to form a new book” [Bush 1991c, 104]. Electro-optical devices borrowed from the Rapid Selector used spinning rolls of microfilm, abstract codes and a mechanical selection-head inside the desk to find and create these links between documents. “This is the essential feature of the Memex. The process of tying two items together is the important thing” [Bush 1991c, 103]. Bush went so far as to suggest that in the future, there would be professional trailblazers who took pleasure in creating useful paths through the common record in such a fashion.

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The Memex described in *As We May Think* was to have permanent trails, and public encyclopaedias, colleague's trails and other information could all be joined and then permanently archived for later use. Unlike the trails of memory, they would never fade. In *Memex Revisited*, however, an adaptive theme emerged whereby the trails were mutable and open to growth and change by Memex itself as it observed the owner's habits of association and extended upon these [Bush 1991d, 213]. After a period of observation, Memex would be given instructions to search and build a new trail of thought, which it could do later “even when the owner was not there” [Bush 1991d, 213]. This technique was in turn derived from Claude Shannon's experiments with feedback and machine learning, embodied in the “mechanical mouse”;

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A striking form of self adaptable machine is Shannon's mechanical mouse. Placed in a maze it runs along, butts its head into a wall, turns and tries again, and eventually muddles its way through. But, placed again at the entrance, it proceeds through without error making all the right turns. [Bush 1991b, 171]

In modern terminology, such a machine is called an intelligent “agent”, a concept we shall discuss later in this work. Technology has not yet reached Bush's vision for adaptive associative indexing [Meyrowitz 1991, 289], although

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intelligent systems, whose parameters change in accordance with the user's experiences, come close. This is called machine learning. Andries van Dam also believes this to be the natural future of hypertext and associative retrieval systems [Van Dam 1999].

In *Memex II*, however, Bush not only proposed that the machine might learn from the human via what was effectively a cybernetic feedback loop — he proposed that the *human might learn from the machine*. As the human mind moulds the machine, so too the machine “remolds” the human mind, it “remolds the trails of the user’s brain, as one lives and works in close interconnection with a machine” [Bush 1991b, 178].

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For the trails of the machine become duplicated in the brain of the user, vaguely as all human memory is vague, but with a concomitant emphasis by repetition, creation and discard ... as the cells of the brain become realigned and reconnected, better to utilize the massive explicit memory which is its servant. [Bush 1991b, 178]

This was in line with Bush’s conception of technical machines as mechanical teachers in their own right. It was a “proposal of an active symbiosis between machine and human memory” [Nyce 1991, 122] which has been surprisingly ignored in contemporary readings of the design. Nyce and Kahn pay it a full page of attention, and also Nelson, who has always read Bush rather closely [Nelson 1999]. But aside from that, the full development of this concept from Bush’s work has been left to Doug Engelbart.

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In our interview, Engelbart claimed it was Bush’s concept of a “co-evolution” between humans and machines, and also his conception of our human “augmentation system”, which inspired him [Engelbart 1999]. Both Bush and Engelbart believe that our social structures, our discourses and even our language can and should “adapt to mechanization” [Bush 1991d, 210]; all of these things are inherited, they are learned. This process is not only unavoidable, it is desirable. Bush also believed machines to have their own logic, their own *language*, which “can touch those subtle processes of mind, its logical and rational processes” and alter them [Bush 1991b, 177]. And the “logical and rational processes” which the machine connected with were *our own memories* — a prosthesis of the inside. This vision of actual human neurons changing to be more like the machine, however, would not find its way into the 1967 essay [Nyce 1991, 122].

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Paradoxically, Bush also retreats on this close alignment of memory and machine. In the later essays, he felt the need to demarcate a purely “human” realm of thought from technics, a realm uncontaminated by technics. One of the major themes in *Memex II* is defining exactly what it is that machines can and cannot do.

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Two mental processes the machine can do well: first, memory storage and recollection, and this is the primary function of the Memex; and second, logical reasoning, which is the function of the computing and analytical machines. [Bush 1991b, 178]

Machines can remember better than human beings can — their trails do not fade, their logic is never flawed. Both of the “mental processes” Bush locates above take place within human thought, they are forms of internal “repetitive” thought [Bush 1991e, 189] — perfectly suited to being externalised and improved upon by technics. But exactly what is it that machines *can’t* do? Is there anything inside thought which is purely human? Bush demarcates “creativity” as the realm of thought that exists beyond technology.

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How far can the machine accompany and aid its master along this path? Certainly to the point at which the master becomes an artist, reaching into the unknown with beauty and versatility, erecting on the mundane thought processes a thing of beauty ... this region will always be barred to the machine. [Bush 1991b, 183]

Bush had always been obsessed with memory and technics, as we have explored. But near the end of his career, when *Memex II* and *Memex Revisited* were written, he became obsessed with the “boundary” between them, between what is personal and belongs to the human alone, and what can be or *already is* automated within thought.

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In all versions of the Memex essay, the machine was to serve as a personal memory support. It was not a *public*

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database in the sense of the modern Internet: it was first and foremost a private device. It provided for each person to add their own marginal notes and comments, recording reactions to and trails from others' texts, and adding selected information and the trails of others by "dropping" them into their archive via an electro-optical scanning device. In the later adaptive Memex, these trails fade out if not used, and "if much in use, the trails become emphasized" [Bush 1970, 191] as the web adjusts its shape mechanically to the thoughts of the individual who uses it.

Current hypertext technologies are not quite so private and tend to emphasise "systems which are public rather than personal in nature and that emphasize the static record over adaptivity" [Oren 1991, 320] due to the need for mass production, distribution and compatibility. The idea of a "personal" machine to amplify the mind also flew in the face of the emerging paradigm of human-computer interaction that reached its peak in the late 1950s and early 1960s, which held computers to be rarefied calculating machines used only by qualified technicians in white lab coats in air-conditioned rooms at many degrees of separation from the "user". "After the summer of 1946", writes Ceruzzi, "computing's path, in theory at least, was clear" [Ceruzzi 1998, 23]. Computers were, for the moment, impersonal, institutionally aligned and out of the reach of the ignorant masses who did not understand their workings. They lived only in university computer labs, wealthy corporations and government departments. Memex II was published at a time when the dominant paradigm of human-computer interaction was sanctified and imposed by corporations like IBM, and "it was so entrenched that the very idea of a free interaction between users and machines as envisioned by Bush was viewed with hostility by the academic community" [De Landa 1994, 219].

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In all versions of the essay, Memex remained profoundly uninfluenced by the paradigm of digital computing. As we have explored, Bush transferred the concept of machine learning from Shannon — but not information theory. He transferred neural and memory models from the cybernetic community — but not digital computation. The analogue computing discourse Bush and Memex created never "mixed" with digital computing [Bush 1970, 208]. In 1945, Memex was a direct analogy to Bush's conception of human memory; in 1967, after digital computing had swept engineering departments across the country into its paradigm, Memex was still a direct analogy to human memory. It mirrored the technique of association in *its mechanical workings*.

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While the pioneers of digital computing understood that machines would soon accelerate human capabilities by doing massive calculations, Bush continued to be occupied with extending, through replication, human mental experience. [Nyce 1991, 124]

Consequently, the Memex redesigns responded to the advances of the day quite differently to how others were responding at the time. By 1967, for example, great advances had been made in digital memory techniques. As far back as 1951, the Eckert-Mauchly division of Remington Rand had turned over the first "digital" computer with a stored-program architecture, the UNIVAC, to the US Census Bureau [Ceruzzi 1998, 27]. "Delay Lines" stored 1,000 words as acoustic pulses in tubes of mercury, and reels of magnetic tapes which stored invisible bits were used for bulk memory. This was electronic digital technology, and did not mirror or seek to mirror "natural" processes in any way. It steadily replaced the most popular form of electro-mechanical memory from the late 1940s and early 1950s: drum memory. This was a large metal cylinder which rotated rapidly beneath a mechanical head, where information was written across the surface magnetically [Ceruzzi 1998, 38]. In 1957, disk memory had been produced, for the IBM305 RAMAC, and rapid advances were being made by IBM and DEC [Ceruzzi 1998, 196].

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Bush, however, remained enamoured of physical recording and inscription. His 1959 essay proposes using organic crystals to record data by means of phase changes in molecular alignment. "[I]n Memex II, when a code on one item points to a second, the first part of the code will pick out a crystal, the next part the level in this, and the remainder the individual item" [Bush 1991b, 169]. This was new technology at the time, but certainly not the direction commercial computing was taking via DEC or IBM. Bush was fundamentally uncomfortable with digital electronics as a means to store material. "The brain does not operate by reducing everything to indices and computation", Bush wrote [Bush 1991e, 190]. Bush was aware of how out of touch he was with emerging digital computing techniques, and this essay bears no trace of engineering details whatsoever, details which were steadily disappearing from all his published work. He devoted the latter part of his career to frank prophecy, reading from the technologies he saw around him and taking "a long look ahead" [Bush 1991b, 166]. Of particular concern to him was promoting Memex as the technology of the

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future, and encouraging the public that “the time has come to try it again” [Bush 1991b, 166].

Memex, Inheritance and Transmission

No memex could have been built when that article appeared. In the quarter-century since then, the idea has been with me almost constantly, and I have watched new developments in electronics, physics, chemistry and logic to see how they might help bring it to reality [Bush 1970, 190].

Memex became an image of potentiality for Bush near the end of his life. In the later essays, he writes in a different tone entirely: Memex was an image he would bequeath to the future, a gift to the human race. For most of his professional life, he had been concerned with augmenting human memory, and preserving information that might be lost to human beings. He had occasionally written about this project as a larger idea which would boost “the entire process by which man profits by his inheritance of acquired knowledge” [Bush 1991c, 99]. But in *Memex II*, this project became grander, more urgent — the idea itself far more important than the technical details. He was nearing the end of his life, and Memex was still unbuilt. Would someone eventually build this machine? He hoped so, and he urged the public that it would soon be possible to do this, or at least, the “day has come far closer” [Bush 1970, 190]: “in the interval since that paper [*As We May Think*] was published, there have been many developments ... steps that were merely dreams are coming into the realm of practicality” [Bush 1991b, 166]. Could this image be externalised now, and live beyond him? It would not only carry the wealth of his own knowledge beyond his death, it would be like a gift to all mankind. In fact, Memex would be the centrepiece of mankind’s *true revolution* — transcending death.

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Can a son inherit the memex of his father, refined and polished over the years, and go on from there? In this way can we avoid some of the loss which comes when oxygen is no longer furnished to the brain of the great thinker, when all the patterns of neurons so painstakingly refined become merely a mass of protein and nucleic acid? Can the race thus develop leaders, of such power and intellect, and such forces of conviction, that the world can be saved from its follies? This is an objective of far greater importance than the conquest of disease, even than the conquest of mental aberrations [Bush 1991b, 183].

Near the end of his life, Bush thought of Memex as more than just an *individual’s* machine; the “ultimate [machine] is far more subtle than this” [Bush 1991b, 182]. Memex would be the centrepiece of a structure of inheritance and transmission, a structure that would accumulate with each successive generation. In *Science Pauses*, Bush entitled one of the sections “Immortality in a machine” [Bush 1991e, 189]: it contained a description of Memex, but this time there was an emphasis on its “longevity” over the individual human mind [Bush 1991e, 190]. This is the crux of the matter; the trails in Memex would not grow old, they would be a gift from father to son, from one generation to the next.

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Bush died on June 30, 1974. The image of Memex has been passed on beyond his death, and it continues to inspire a host of new machines and “technical instrumentalities”. But Memex itself has never been built; it exists only on paper, in technical interpretation and in memory. All we have of Memex are the words that Bush assembled around it in his lifetime, the drawings created by the artists from *Life*, its erotic simulacrum, its ideals, its ideas. Had Bush attempted to assemble this machine in his own lifetime, it would undoubtedly have changed in its technical workings; the material limits of microfilm, of photoelectric components and later, of crystalline memory storage would have imposed their limits; the “use function” of the machine would itself have changed as it demonstrated its own potentials. If Memex had been built, the object would have invented itself independently of the outlines Bush cast on paper. This never happened — it has entered into the intellectual capital of new media as an image of potentiality.

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Works Cited

Bagg and Stevens 1961 Warning: Biblio formatting not applied. Bagg T. C. Stevens M. E. *Information Selection Systems Retrieving Replica Copies: A state-of-the-art report. National Bureau of Standards Technical note 157.* Washington, D.C. Government Printing Office. 1961.

Beniger 1986 Beniger, James R. *The Control Revolution: Technological and Economic Origins of the Information Society.* Cambridge, MA: Harvard University Press, 1986.

Burke 1991 Burke, Collin. “A Practical View of the Memex: The Career of the Rapid Selecto”. In James Nyce and Paul

- Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991.
- Bush 1928** Bush, Vannevar. "Mechanical Solutions of Engineering Problems". *Tech Engineering News* 9 (1928).
- Bush 1939** Warning: Biblio formatting not applied. BushVannevar. *Mechanization and the Record*. *Vannevar Bush Papers*. Box 138, Speech Article Book File. Washington D.C. Library of Congress. 1939.
- Bush 1963** Warning: Biblio formatting not applied. BushVannevar. *Man's Thinking Machines*. *Vannevar Bush Papers*. MC78, Box 21. Cambridge, MA. MIT Archives. 1963.
- Bush 1970** Bush, Vannevar. *Pieces of the Action*. New York: William Morrow, 1970.
- Bush 1991a** Bush, Vannevar. "The Inscrutable 'Thirties'". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 67-80.
- Bush 1991b** Bush, Vannevar. "Memex II". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 165-184.
- Bush 1991c** Bush, Vannevar. "As We May Think". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 85-112.
- Bush 1991d** Bush, Vannevar. "Memex Revisited". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 197-216.
- Bush 1991e** Bush, Vannevar. "Science Pauses". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 185-196.
- Ceruzzi 1998** Ceruzzi, Paul E. *A History of Modern Computing*. Cambridge, MA: MIT Press, 1998.
- De Landa 1994** De Landa, Manuel. *War in the Age of Intelligent Machines*. New York: Zone Books, 1994.
- Dennett 1993** Dennett, Daniel C. *Consciousness Explained*. London: Penguin Books, 1993.
- Edwards 1997** Edwards, Paul N. *The Closed World: Computers and the Politics of Discourse in Cold War America*. Cambridge, MA: MIT Press, 1997.
- Eldredge 2004** Eldredge, Niles. Email interview with Belinda Barnet. March 2004.
http://journal.fibreculture.org/issue3/issue3_barnet.html.
- Engelbart 1999** Engelbart, Douglas. Interview with Belinda Barnet. November 10, 1999.
- Farkas-Conn 1990** Farkas-Conn, Irene S. *From Documentation to Information Science: The Beginnings and Early Development of the American Documentation Institute—American Society for Information Science*. New York: Greenwood Press, 1990.
- Gille 1986** Gille, Bertrand. *History of Techniques*. New York: Gordon and Breach Science Publishers, 1986.
- Guattari 1995** Guattari, Félix. *Chaosmosis: An Ethico-Aesthetic Paradigm*. Translated by Paul Bains and Julian Prefanis. Sydney: Power Publications, 1995.
- Hartree 2000** HartreeDouglas. *Differential Analyzer*.
<http://athena.union.edu/~hemmendd/Encyc/Articles/Difanal/difanal.html>.
- Hatt 1968** Hatt, Harold. *Cybernetics and the Image of Man*. Nashville: Abingdon Press, 1968.
- Hayles 1993** Hayles, N. Katherine. "Virtual Bodies and Flickering Signifiers". *October Magazine* 66 (Fall 1993), pp. 69-91.
- Hayles 1999** Hayles, N. Katherine. *How we Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press, 1999.
- Hazen 1940** Warning: Biblio formatting not applied. HazenHarold. *MIT President's report*. 1940. MIT President's report.
- Meyrowitz 1991** Meyrowitz, Norman. "Hypertext: Does it Reduce Cholesterol, Too?". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 287-318.
- Mindell 2000** MindellDavid A. *MIT Differential Analyzer*. <http://web.mit.edu/mindell/www/analyzer.htm>.
- Nelson 1991** Nelson, Theodor H. "As We Will Think". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 245-260.

Nelson 1999 Nelson, Theodor H. Interview with the author.

Nyce 1991 Nyce, James, and Paul Kahn, eds. *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991.

Oren 1991 Oren, Tim. "Memex: Getting Back on the Trail". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 319-338.

Owens 1991 Owens, Larry. "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 3-38.

Shurkin 1996 Shurkin, Joel. *Engines of the Mind, The Evolution of the Computer from Mainframes to Microprocessors*. New York: WW Norton and Company, 1996.

Smith 1991 Smith, Linda C. "Memex as an Image of Potentiality Revisited". In James Nyce and Paul Kahn, eds., *From Memex to Hypertext: Vannevar Bush and the Mind's Machine*. London: Academic Press, 1991. pp. 261-286.

Spar 2001 Spar, Debora L. *Ruling the Waves: Cycles of Discovery, Chaos, and Wealth from Compass to the Internet*. New York: Harcourt, 2001.

Stiegler 1998 Stiegler, Bernard. *Technics and Time, 1: The Fault of Epimetheus*. Stanford: Stanford University Press, 1998.

Van Dam 1999 Van Dam, Andries. Interview with the author.

Weaver 1950 Weaver, Warren. Project diaries. March 17, 1950.

Weaver 1950a Warning: Biblio formatting not applied. WeaverWarren. *Letter to Samuel Caldwell*. RF1.1/224/2/26. Sleepy Hollow, NY. Rockefeller Archive Center. 1950.

Wells 1938 Wells, H.G. *World Brain*. London: Methuen & Co. Limited, 1938.

Ziman 2003 Ziman, John. *Technological Innovation as an Evolutionary Process*. Cambridge: Cambridge University Press, 2003.



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