Extreme Inscription: Towards a Grammatology of the Hard Drive[1]

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Abstract

"Extreme Inscription" attempts to articulate the grammatological primitives of the hard drive, the inscription technology that has had the single greatest impact on computing in the latter half of the 20th century. Rather than offer up yet another generalized account of electronic textuality, my objective in this essay is to examine one specific writing machine in its unique social, technical, and imaginative milieu. Random access disk storage, I argue, is the technology that embodies the "database paradigm" a critic such as Lev Manovich sees as fundamental to new media. The history of hard drive technology is treated in the essay, as is the cultural impact of new hard drive-based technologies like iPod, TiVo, and Gmail's massive multi-gigabyte quotas. Ultimately the article seeks to establish a place for the often invisible and certainly unglamorous presence of storage technologies amid the largely visual and screen-based approaches that currently prevail in new media theory.

> "Had however this friction really existed, in the many centuries that these heavens have revolved they would have been consumed by their own immense speed of every day ... we arrive therefore at the conclusion that the friction would have rubbed away the boundaries of each heaven, and in proportion as its movement is swifter towards the center than toward the poles it would be more consumed in the center than at the poles, and then there would not be friction anymore, and the sound would cease, and the dancers would stop ..."
> --Leonardo da Vinci, *The Notebooks*, F 56 V

> "One Monday morning, one of my customers had their WIN NT 3.51 server hard drive crash. It was a head crash, you could hear the heads riding the platter. An awful noise

... I spent 16 hours pulling data from that hard drive, and once I was done (I had pulled as much data as I could) we opened up the drive to discover that the head on the bottom platter had fallen down, and had been riding there over the weekend. It had etched away at the platter for so long that the platter had actually fallen down and was sitting in a pile of ... shavings at the bottom of the drive."
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As a written trace digital inscription is invisible to the eye, but it is not instrumentally undetectable or physically immaterial. Saying so is not a theoretical proposition but a discernible fact, born of the observable behavior of some 8.5 million terabytes of storage capacity brought to market in one recent year alone.[2]

I am referring to the devices we call hard drives. The hard drive and magnetic media more generally are mechanisms of *extreme* inscription -- that is, they offer a practical limit case for how the inscriptive act can be imagined and executed. To examine the hard drive at this level is to enter a looking glass world where the Kantian manifold of space and time is measured in millionths of a meter (called microns) and thousandths of a second (milliseconds), a world of leading-edge engineering rooted in the ancient science of tribology -- the study of interacting surfaces in relative motion. Rather than offer up yet another generalized account of electronic textuality, my objective in this essay is to examine one specific digital writing technology in its unique social, technical, and imaginative milieu, and thereby connect to the new histories of inscription being pursued by such diverse critics as Friedrich Kittler, Lisa Gitelman, Bruce Clarke, Bruno Latour, Timothy Lenoir, Patricia Crain, and Adrian Johns.[3] Put another way, "the computer" as a generic appellation is not adequate as a starting point for the kind of investigation of electronic writing I have in mind, any more than "the book," conceived as a homogenous form, suffices for serious students of earlier periods of textuality. Here we will follow the bits all the way down to the metal.[4]

As students of old new media such as Friedrich Kittler or more recently Lisa Gitelman see so clearly, writing for quite some time now has meant more than alphabetization, and writing machines do more than make and mark letterforms. One way of understanding a writing technology, notes Gitelman, is as an artifact of a culture's "consensual, embodied

theories of language" (5). I will not be advancing quite such an ambitious claim for the hard drive here, but I hope something of the idea suggests itself in the pages that follow.[5]

Some may object that my focus on hard drives is arbitrary or tendentious. The personal computer era was well underway without them, and even in industry, magnetic tape -- not the more expensive disks -- was the preferred storage mode until quite recently. They are also, of course, are by no means the only storage media in common use today, and many believe they will be supplanted, if not by solid state or laser optical devices then by more advanced techniques such as holography. Nonetheless, hard disk drives have been the primary storage media for personal computers since the mid-1980s, and also for countless internet and intranet servers; though their speed, capacity, and reliability have all increased dramatically -- increases in the capacity of disks has in fact outstripped the famous Moore's Law for processor speeds -- basic drive technology remains remarkably unchanged since it was first introduced by IBM in the 1950s. The hard drive is therefore central to any narrative of computing and inscription in the latter half of the twentieth-century, yet it has never received extended consideration from scholarly observers of new media. [6]

Indeed, inscription was explicitly written out of what may be the very first full-length critical treatment of electronic writing, Michael Heim's *Electric Language: A Philosophical Discussion of Word Processing* (1987):

> After the first five months most people who write on computers are enraptured: "This is bliss. Here is true freedom. No more cutting paper and pasting, no more anxiety over revisions. Now I can get to work without the nuisance of typing and re-typing." They feel the thrill of the electric speed of automation applied to the production of printed pages. Yet, in order to achieve such automation, *writing has to be removed from the element of inscription* and placed in an electronic element. (136; emphasis added)

In this account, which precedes the better-known books by Lanham, Landow, and Bolter, Heim puts his finger on many of the most salient aspects of the personal computer as a writing technology, for example what he terms "system opacity":

The types of physical cues that naturally help a user make sense out of mechanical movements and mechanical connections are simply not available in the electronic element. There are far more clues to the underlying structural processes for the person riding a bicycle than there are for the person writing on a computer screen. Physical signs of the ongoing process, the way that responses of the person are integrated into the operation of the system, the source of occasion blunders and delays, all these are hidden beneath the surface of the activity of digital writing. No pulleys, springs, wheels, or levers are visible; no moving carriage returns indicate what the user's action is accomplishing and how that action is related to the end product; and there is no bottle of white-out paint complete with miniature touch-up brush to betoken the industrial chore of correcting errors by imposing one material substance over another. The writer has no choice but to remain on the surface of the system underpinning the symbols. (131-2)

Hard disk drives, which had only just entered the personal computer market when Heim's book was published, are no exception. Despite (or really because of) their being the most overtly mechanical component of the computer, they are physically sequestered from any direct observation. The drive resides within the machine's external case and is further isolated inside of a specially sealed chamber to keep out dust, hair, and other contaminants. When a drive is opened for repair or data recovery the work is done in a clean room, similar to those used to print microprocessors. Most users will never see their hard drive during the life of their computer. As a writing instrument it thus remains an abstraction, or else apprehended through aural rather than visual cues (the drive is audible as it spins up or down). That the physical seclusion of the hard drive renders it an almost literal black box should not be underestimated in the extent to which its mechanism has gone unremarked in discussions of electronic textuality. As Gitelman observed of early typewriters, which only brought a line of text into view after the next line had been typed, "[t]he machine's upstrike design seemed to refute the possibility of error, however unrealistically, and in removing the act of inscription from the human eye seemed to underscore its character as a newly technological and automatic event" (206). The hard drive occupies a similar position I would argue, only one

that is subject to vastly more complex forms of instrumentation and mediation. Since hard disks, in most users' experience, either work flawlessly or else crash spectacularly, the notion of the device as a binary black box with no capacity for error short of global failure is perhaps inevitable. But these functional extremes are precisely what reinforce the dominant perception of immateriality.[7]

Little wonder then that electronic writing's first generation of theorists turned their gaze toward the screen rather than the disk. The cathode ray tube was the implicit and often explicit starting point for most discussions of electronic textuality because it was only as bit-mapped fonts on the screen that electronic letterforms become recognizable as writing. N. Katherine Hayles, in a widely read essay entitled "Virtual Bodies and Flickering Signifiers," published in 1993 puts it this way: "Working at the computer screen, I cannot read unaided the magnetic markers that physically embody the information within the computer, but I am acutely aware of the patterns of blinking lights that comprise the text in its screen format" (260).[8] Hayles, of course, fully apprehends the internal complexity of the symbolic transaction she is alluding to here, noting elsewhere that the screen's "flickering signifiers" (as she calls them, after Lacan) originate as magnetic traces on a disk, which are then interpolated through binary machine language, compiler, application software, and so forth (264). The basic thesis Hayles goes on the develop, that signification in electronic environments involves "a flexible chain of markers bound together by the arbitrary relations specified by the relevant codes" (264), effectively captures what most users experience as the basic phenomenological difference between analog and digital media (whether backspacing to correct a typing error or brightening an image in Photoshop). Digital signification, in this model, consists in an open-ended symbiotic exchange (or feedback loop) between computation and representation.

Nick Montfort has recently coined the term "screen essentialism" to refer to the bias towards monitors and display devices in new media studies, where the vast preponderance of critical attention has been focused on what happens on the windowed panes of the looking glass. This is, as Montfort points out, a historically top-heavy approach; screens would have been unknown to most users before the mid-1970s (the teletype was the dominant output device).[9] I believe that if we expand its definition to include machine-language markings and machine-readable inscriptions as well as alphanumerical writing, then the history and theory of electronic textuality must come to encompass more than just the screen-deep

flickering signifiers that have thus far occupied critics in their investigations of new media. The essay that follows develops one instance of what this kind of electronic textual criticism might look like.

"This Has Been a Day of Solid Achievement"

Among the attractions at the 1958 World's Fair in Brussels, Belgium, visitors would have beheld Professor RAMAC, a four-ton IBM machine capable of offering up responses to users' queries on a two thousand year historical span ranging from "... the birth of Christ to the launching of Sputnik 1."[10] Described as an "electronic 'genius'" with "almost total historical recall and the ability to speak 10 languages" the Professor offered the general public its first encounter with the magnetic disk storage technology today called the hard drive. Technically known as the RAMAC 305, the machine had been developed at IBM a few years earlier and was then in use by a handful of corporate clients, notably United Airlines.[11] It was typically paired with an IBM 650, a general-purpose business computer. The RAMAC was capable of storing five million 7-bit characters on 50 vertically stacked disks, each two feet wide and rotating at 1200 RPM. In contemporary parlance this means that the first hard drive had a capacity of about 5 megabytes. The machine leased for $3200 a month, ran on vacuum tubes, and was taken off the market by 1961; some 1500 were manufactured in all.

When the RAMAC was first announced in 1956, Thomas J. Watson, Jr., President of IBM, opined that it was "the greatest product day in the history of IBM."[12] The remark was arguably not an overstatement. The RAMAC, which stood for Random Access Memory and Control, was, as its name implies, a random access storage device. This was fundamentally different from the punched paper or magnetic tape that then dominated computer storage. As Paul E. Ceruzzi notes, "[i]n time, the interactive style of computing made possible by random access disk memory would force IBM, as well as the rest of the computer industry, to redefine itself" (70).[13] This is a powerful insight, and not often grasped by students of new media who tend to ascribe "interactivity" to the advent of the screen display, the graphical user interface, and the mouse in a genealogy that runs from the SAGE air defense network through Ivan Sutherland's Sketchpad to Douglas Englebart's 1968 "mother of all demos." But the advent of random access disk storage goes to the heart of contemporary critical assumptions about new media. For Lev Manovich for example,

new media productions are best characterized by a "database paradigm," manifested in the discrete nature of their constituent objects and the lack of an essential narrative or sequential structure for how those objects are accessed and manipulated: "In general, creating a work in new media can be understood as the construction of an interface to a database" (226).[14] While Manovich is reluctant to associate database and narrative with specific storage technologies in any deterministic sense -- the codex book, he notes, is the random access device *par excellence*, yet it is a haven for some of our most powerful narrative forms (233) -- computers could not have expanded in their role from war-time calculators to new media databases without the introduction of a non-volatile, large-volume, inexpensive technology that afforded operators near-instantaneous access to stored records. Magnetic disk media, more specifically the hard disk drive, was to become that technology and, as much as bitmapped-GUIs and the mouse, usher in a new era of interactive, real-time computing.[15]

But first let us return to the IBM pavilion in Brussels where, according to the press kit:

> Visitors to the fair will be able to ask the machine what were the most important historical events in any year from 4 B.C. to the present and RAMAC will print out the answers on an electronic typewriter in a matter of seconds.... A query to the professor on what events took place in the year 30 A.D., for example, would yield answers like this: "Salome obtained the head of Saint John the Baptist." In 1480? "Leonardo da Vinci invented the parachute." In 1776? "Mozart composed his first opera at the age of 11."[16]

There are several observations to make here, starting with the Professor's title and vocation. In 1950 Edmund C. Berkeley had published a book entitled *Giant Brains: or Machines That Think*, the first work to introduce computers to a general audience. The shift from Berkeley's anthropomorphism to the RAMAC's full-fledged personification as a "professor" or "genius" hints at the kinds of synthetic identities that would culminate with Arthur C. Clarke's HAL 9000 only a decade later. Second, we should note that while the Professor's "almost total historical recall" was strictly hardwired, the notion of a computer endowed with the kind of encyclopedic capacity we today take for granted in an era of world wide webs

and electronic archives would have then seemed quite novel. Much of the American public, for example, had first encountered computers during the 1952 presidential campaign, when the UNIVAC 5 (correctly) forecast Eisenhower's victory over Adlai Stevenson a month ahead of time on live TV. Computers were thus on record as instruments of prediction and prognostication, not retrospection. The RAMAC, by contrast, represented what was perhaps the first digital library. Its multi-lingual capability, a brute force flourish clearly meant to impress, is also worth a comment: in the context of the World's Fair it no doubt served to reinforce the machine's identity as a global citizen, its omniscient command of the human record and status as an impartial observer -- at least until one realized that with the exception of Interlingua, an artificial language, all of the languages in question were those of the major European or imperial powers.[17] As perhaps the earliest computational personality on record (almost a decade before Weizenbaum's ELIZA), the Professor was thus marked out as a first-world citizen of a post-colonial present rather than as a trans-historical remember of things past.[18]

The problem domain that led to random access disk storage had been succinctly delineated a few years earlier by a government scientist at the National Bureau of Standards named Jacob Rabinow, in a 1952 article for the journal *Electrical Engineering*, on his work with prototypes for a notched-disk magnetic storage system:

> As the operations of government and private business become more varied in nature and larger in scope, the problem of adequate record keeping is continually becoming more acute. Not only is the volume of records rising to unprecedented magnitude, but also the time required to store and later reach this information is becoming continually of greater importance. (745)[19]

The prose here recalls Vannevar Bush, who in a far more famous essay entitled "As We May Think" had seven years earlier used much the same language to describe the impetus behind his Memex, a microfilm-based document management system long celebrated as a prescient anticipation of electronic hypertext. Unlike the Memex however, which was never actually built, magnetic disk storage became an industry reality in just a few short years. Rabinow, for his part, clearly knew something about the history of written text, noting that the "3-dimensional storage of informa-

tion, as in a book, utilizes space most efficiently" (745). His idea was for a structure he described as a "doughnut," consisting of an array of disks suspended in vertical profile to a central spindle on which one or more read/write heads would be mounted; each disk would have a large "notch" that would allow the heads to pass through as the disks rotated about the spindle. This sounds like an eccentric contraption, yet the codex book was an explicit touchstone:

> The notched-disk memory 'doughnut' can be thought of as a kind of book in which round pages are slotted in such a way that each line on each page can be read by merely spinning the page for one revolution; the notches in the pages provide the 'windows' through which the selected page can be read. In other words, the book can be read without being opened. (746)

This is a fascinating passage, one which gives us what is surely one of the very first articulations of the idea of a "digital book." The comparison of disks to pages and of the concentric recording tracks (still a basic feature of magnetic disks today) to lines on the page is also striking, a reminder of the extent to which efficient inscription demands the rationalization of the writing space, regardless of medium. Perhaps most noteworthy, however, is the final line, the "book [that] can be read without being opened."[20] This image, a throwaway, seems to anticipate much in our own contemporary response to electronic storage media: the book has become a black box, and whatever is inscribed within its pages is destined for other than human eyes. Like the telegraph's automatic writing or the "call" of the telephone, the book that can be read without being opened offers up a whiff of the uncanny, the hint of haunted media.[21]

Rabinow's notched-disk doughnut was never brought to market. The solution belonged instead to IBM, which had recently opened a west coast research lab in San Jose under the direction of Reynold B. Johnson, a seasoned inventor who was given an Edison-like mandate to initiate new projects.[22] New storage technologies were high on the priority list. As two IBM executives admitted in 1946, "The problem of electronic storage of numbers during the calculation is of fundamental importance, and we have no adequate solution of the problem."[23] Such statements should be understood in the wake of John von Neumann's "Draft Report on the EDVAC" (1945) -- a sometimes misunderstood text which von Neumann himself

was only partly responsible for authoring -- and its enormously influential articulation of the stored program concept, in which a computer, rather than being "hardwired" with switches and cables, represented both data and one or more programs (instructions for operating on that data) internally. The von Neumann model effectively dictated that there could be no computation without corresponding representation in a physical substratum. Before the technology stabilized with magnetic tape and disk in the late 1950s, all manner of media and materials would be pressed into service to capture and record data: paper cards and tape, but also quartz crystals, glass filament, acoustic pulses in tubes of mercury, coils and loops of wire, magnetic ringlets, drums, doughnuts, plates, and finally disks. This diverse and exotic assortment of materials was then prepared and treated with equally exotic layers of lubricants, coatings, and sealants. (Eventually the engineers at San Jose would borrow the same iron oxide paint that gives the Golden Gate Bridge its distinctive hue to magnetically coat their first disk platters.)[24] Interestingly, one of the leading contenders for data storage prior to magnetic tape and disk was the cathode ray tube, which used electron beams to paint and store lines and dots representing binary numbers. Thus the mainstay of computer screen displays was actually first deployed as a storage solution, not an output device -- a historical irony which makes Montfort's diagnosis of "screen essentialism" for the current situation all the more apt.

A number of key problems needed to be solved in San Jose, not least of them the air bearing technology that would allow the magnetic read/write heads to "float" at a stable distance just above the surface of the spinning platter (more on this in the next section).[25] Nevertheless, on February 10, 1954 researchers successfully transferred a simple English sentence from a punched paper card to a rotating magnetic disk and back again, a sentence that deserves to take its place in technological history alongside of "What hath God wrought," "Mary had a little lamb," and "Mr. Watson -- come here -- want to see you." It is an sentence both quieter and more deliberate than any of these, redolent of Big Blue's corporate pedigree: "This has been a day of solid achievement."[26]

A Grammatology of the Hard Drive

Digital inscription is a form of displacement. Its fundamental characteristic is to remove electronic objects from the channels of direct human observation. This is reflected in even casual language we use to describe

the inscription process. The commonplace is to speak of writing a file to a disk; to say writing "on" a disk sounds vaguely wrong, the speech of someone who has not yet assimilated the relevant vocabulary or concepts. We write on paper, but we write to a magnetic disk (or tape). Part of what the preposition contributes here is a sense of interiority; because we cannot see anything on its surface, the disk is semantically refigured as a volumetric receptacle, a black box with a closed lid. If we were writing on the disk we would be able to see the text, like a label. Instead, the preposition of choice, "to," becomes a marker for our intuition that the verb "write" is not altogether appropriate, a rough fit at best.[27] The preposition is also a legacy of the von Neumann model, where storage is a physically as well as a logically distinct portion of the computer. Writing data "to" the storage element thus entails a literal as well as a conceptual displacement.

What, then, are the essential characteristics -- he grammatological primitives, as it were -- of the hard disk drive as inscription technology? Here is my list: it is *random access*; it is a *signal processor*; it is *differential*; it is *volumetric*; it is *rationalized* (and *atomized*); it is *motion-dependant*; it is *planographic*; and it is *non-volatile* (but also *variable*). I gloss each of these in further detail below, while also explaining something of the technical operation of the drive.[28]

It is *random access*. Like the codex and vertical file cabinets and vinyl records, unlike the scroll or magnetic tape or a filmstrip, hard drives permit (essentially) instantaneous access to any portion of the physical media, without the need to fast-forward or rewind a sequence. Lest there be any doubt about the affinity between these random access technologies, at least one company now markets designer hard drives whose exterior case has the appearance of a handsome cloth-bound book.[29]

It is a *signal processor*. The conventional wisdom is that what gets written to a hard disk is a simple magnetic expression of a bit: a one or a zero, aligned as a north or south polarity. In fact, the process is a highly condensed and complex set of symbolic transformations, by which a "bit," as a binary value in the computer's memory, is converted to a voltage passed through the drive's read/write head where the current creates an electromagnetic field reversing the polarity of not one but several individual magnetic dipoles -- a whole pattern of flux reversals -- embedded in the material substrate of the disk. Likewise, to read data from the surface of the platter, these patterns of magnetic fields (actually patterns of magnetic resistance), which are received as analog signals, are interpreted by the head's detection circuitry as a voltage spike that is then converted into

a binary digital representation (a one or a zero) by the drive's firmware.[30] The relevant points are that writing and reading to the disk is ultimately a form of digital to analog or analog to digital signal processing -- not unlike the function of a modem -- and that the data contained on the disk is a second-order representation of the actual digital values the data assumes for computation.

It is *differential*. The read/write head measures reversals between magnetic fields rather than the actual charge of an individual magnetic dipole. In other words, it is a differential device -- signification depends upon changes in the value of the signal being received rather than the substance of the signal itself. (Readers may recognize similarities to the classic Saussurian model of differential relations in linguistics.)

It is *volumetric*. A hard disk drive is a three-dimensional writing space. The circular platters, sometimes as many as ten, are stacked one atop another, and data is written to both sides (like a vinyl record but unlike a CD-ROM). The physical capacity of a platter to record bit representations is known as its aerial density (sometimes also bit density or data density), and innovations in drive technology have frequently been driven by the desire to squeeze more and more flux reversals onto ever decreasing surface space (for example, IBM now markets a hard disk device called a Mircodrive, a single platter one inch in diameter). Typical aerial densities are now at around 10,000,000,000 bits (not bytes) per square inch. Technologies or techniques that heighten the sensitivity of the drive head's detection circuitry are critical to increasing aerial density because as bits are placed closer and closer together their magnetic fields must be weakened so that they don't interfere with one another; indeed, some researchers speculate that we are about to hit the physical limit of how weak a magnetic field can be and still remain detectable, even by new generations of giant magnetoresistive drive heads and stochastic decoding techniques. It is important to recognize that bit representations have actual physical dimensions at this level, however tiny: measured in units called microns (a millionth of a meter, abbreviated μm), an individual bit representation is currently a rectangular area about 4.0 μm high and .5 μm wide; by contrast, a red blood cell is about 8 μm in diameter, an anthrax spore about 6 μm. Individual bit representations are visible as traceable inscriptions using laboratory instrumentation like Magnetic Force Microscopy.[31] While all storage media, including printed books, are volumetric -- that is, the surface area and structural dimensions of the media impose physical limitations on its capacity to record data -- the history of magnetic

media in particular has been marked by continuous attempts to increase aerial densities.[32]

It is *rationalized*. There is no portion of the volumetric space of the drive that is left unmapped by an intricate planar geometry comprised of tracks (sometimes called cylinders) and sectors. Tracks may be visualized as concentric rings around the central spindle of each platter, tens of thousands of them on a typical disk. Sectors, meanwhile, are the radial divisions extending from the spindle to the platter's edge. The standard size for a sector is 512 bytes or 4096 bits; if we remember that aerial densities of 10,000,000,000 bits per square inch are common, we can get some idea of just how many sectors there in each of the disks many thousands of tracks. Formatting a disk, an exercise which many will have performed with floppies, is the process by which the track and sector divisions -- which are themselves simply flux reversals -- are first written onto the media. There is thus no such thing as writing to the disk anterior to the overtly rationalized gesture of formatting.

Every formatted hard disk stores its own self-representation, a table of file names and addresses known (on Windows systems) as the File Allocation Table (FAT).[33] The FAT, which dates back to DOS, is the skeleton key to the drive's content. It lists every file on the disk, together with its address.[34] (The ubiquitous eight character/three character file naming convention of DOS and early Windows systems was an artifact of the FAT.) The basic unit for file storage is not the sector but rather clusters, larger groupings of typically 32 or 64 contiguous sectors in a track. Since the size of a file rarely corresponds exactly to a multiple of the size of a cluster, most files have empty sectors appended after the logical end of the file -- these unused sectors are called slack space and sometimes contain the forensic remains of previous files. Clusters, furthermore, are not necessarily contiguous; larger files may be broken up into clusters scattered all over volumetric interior of the drive. (In a very basic way then, all electronic data is "hypermedia" to the FAT.) Defragmenting a disk is the process of moving far flung clusters physically closer to one another in order to improve the performance of the drive (since the only active mechanical motion the slider arm performs is moving the heads from one track to another, the more this motion can be kept to a minimum the faster the disk array's access times). The FAT -- itself a purely textualized construct—and the data structures it maps, is arguably the apotheosis of a rationalization and an *atomization* of writing space that began with the discrete pages of another random access device, the codex.[35]

It is *motion-dependent*. As many commentators have pointed out computing is a culture of speed, and hard drives are no exception. Motion and raw speed are integral aspects of their operation as inscription technologies. Once the computer is turned on, the hard disk is in near constant motion. The spindle motor rotates the platters at up to 10,000 revolutions per minute.[36] This motion is essential to the functioning of the drive for two reasons. First, while the read/write head is moved laterally across the platter by the actuator arm when seeking a particular track, the head depends upon passive motion to access individual sectors: that is, once the head is in position at the appropriate track it simply waits for the target sector to rotate past. (Platters spin counter-clockwise, meaning that the head actually reads and writes right to left.) The rotation of the disk is what allows the head to detect reversals in the magnetic fluctuations on the surface of the platter (see *differential*, above). Motion is also fundamental to the operation of the drive in a second and even more basic sense. Unlike other forms of magnetic media such as video or audio tape, or even floppy disks, where the read/write heads physically touch the surface of the recording medium, the head of a hard disk drive "flies" above the platter at a distance a tiny fraction of the width of a human hair. (The actual distances are measured in units called nanometers. Earlier we encountered microns; one micron equals 1000 nanometers. Thus, even the length and breadth of bit representations vastly exceed the flying height of the drive head.) The rapid motion of the disk creates an air cushion that floats the head of the drive. Just as a shark must swim to breathe, a hard drive must be in motion to receive or return data. This air bearing technology, as it is called (pioneered by IBM at San Jose in the 1950s), explains why dust and other contaminants must be kept out of the drive casing at all costs. If the heads touch the surface of the drive while it is in motion the result is what is known as a head crash: the head, which it must be remembered is moving at speeds upward of one hundred miles per hour, will plow a furrow across the platter, and data is almost impossible to recover. Thus, a key aspect of the hard drive's materiality as an agent of digital inscription is quite literally created out of thin air.

It is *planographic*. Material surfaces for writing and inscription can be broadly classified in one of three ways, depending on the altitudinal relationship of the meaning-bearing marks and traces to the media that supports them. Relief processes, like woodcuts and letterpress type, rely on raised height to transfer marks from one surface to another; intaglio processes, like etching and engraving, rely on indentation, holding

ink in grooves where it is transferred by the downward force of a press; planographic surfaces are a relative latecomer, and are exemplified by lithography, which uses a mixture of grease and water to separate ink on the smooth surface of a printing stone. Hard drives are planographic in that the surface of the disk, in order to fly scant nanometers beneath the air bearings, must be absolutely smooth. The platter which supports the magnetic layer where read/write operations take place has traditionally been made of aluminum; more recently production is shifting to glass (as in silicon).[37]

It is *non-volatile* (but *variable*). Though magnetic media are subject to physical deterioration it is stable and durable over time.[38] Just how much effort is required to completely erase a hard drive, and whether this is best done by way of magnetic fields (degaussing), overwriting the data, or more extreme measures is something of a black art and not fully understood, at least to the general public.[39] The US Department of Defense unabashedly recommends the following: "Destroy -- disintegrate, incinerate, pulverize, shred or smelt."[40] It is true, however, that data is routinely recovered from hard drives that have been subjected to fire, flood, and even more extraordinary circumstances -- a German firm successfully recovered data from hard drives salvaged from the ruins of the World Trade Center, for example.[41] Far from being fragile or ephemeral, the magnetic substrate of a drive is one of the stickiest and most persistent surfaces for inscription we've ever devised.

Paradoxically, however, just as important is the fact that the same volumetric area on the surface of the disk can be recycled and rewritten. The ability to erase and change data rapidly was in fact a key characteristic of the computer as envisioned by pioneers like Norbert Wiener.[42] This in turn situates hard drives and magnetic media within a millennia-long trajectory of a search for erasable writing technologies, which includes wax tables, graphite pencils, and correctible typewriter ribbons. Therefore, alongside of its non-volatility, we must also acknowledge magnetic media's *variability*. Interestingly, holographic storage, which some see as eventually replacing magnetic media -- data is stored in a solid array of crystals -- is not generally reusable.[43] (One speculation is that holographic storage will be so cheap and capacious that it will not be functionally or economically necessary to ever erase *anything*.) Such a technology would explode current conventions of data storage, re-conceiving human computer interaction as fundamentally as random-access non-volatile (but variable) storage media did in the 1950s. Indeed, as we will see in the next

section, there are strong indications that something very much like this is already happening.

"You Are Your C": Reading/Writing Storage

Storage: the word itself is dull and flat sounding, like footfalls on linoleum. It has a vague industrial aura -- tape farms under the fluorescents, not the Flash memory sticks that are the skate-keys of the wifi street. Yet storage technologies have never been more important than they are now in shaping the material experience of computing, interactivity, and new media. Some signs of the times:

> 1. Mark Bernstein, long-time hypertext theorist and developer, muses in his blog: "From time to time, I tidy up my hard disk. I delete useless old files and excess Tinderbox notes. I weed out the worst snapshots, the redundant images and the blurred pictures and the pictures I accidentally took of someone's feet. This is probably a mistake. It often costs more to decide to throw something away than to save it forever" (emphasis in original).[44]
> 2. Google launches its Gmail service, having apparently arrived at much the same set of conclusions. All new users receive the following advice: "Archive, don't delete: With 1000 megabytes of free storage, you'll never need to delete another email. Just archive everything and use Gmail's search to find what you need." As of this writing, Google in fact offers users 2 gigabytes of storage.
> 3. Information scientist Michael Lesk, well known for his regular "How Much Information Is There in the World" reports, concludes that the total annual media output of the planet now amounts to "1.5 exabytes of storable content ...This is 1.5 billion gigabytes, and is equivalent to 250 megabytes for every man, woman, and child on earth." Lesk arrives at his figures by quantifying media such as books, photographs, film, and music. He notes that shipped hard drive capacity, which doubles every year, easily accommodates that figure, and that "magnetic storage is rapidly becoming the universal medium for information storage."[45] Meanwhile, industry experts such as

Brian Hayes point out that at current levels of production 120 terabyte drives will be on the market by 2012, even though others, such as Seagate's Mark Kryder, suggest that the superparamagnetic limit—the smallest physical space that can retain a magnetic charge, measured at the nanoscale -- will be reached at around 20 terabytes.[46]

4. A glimpse of this future is perhaps to be found in Microsoft researcher Gorden Bell's MyLifeBits project, described as "a lifetime store of *everything...* Gordon Bell has captured a lifetime's worth of articles, books, cards, CDs, letters, memos, papers, photos, pictures, presentations, home movies, videotaped lectures, and voice recordings and stored them digitally. He is now paperless, and is beginning to capture phone calls, television, and radio."[47] Tellingly, Bell's MyLifeBits is actually described as a database project, with a research agenda defined by problems of indexing, accessing, and annotating the massive volume of information that is collected. Data mining, technologies that utilize machine-learning algorithms to iterate over vast reserves of archival data in search of unexpected patterns and associations, is a direct outgrowth of the massive quantities of random access storage available from magnetic disks.

Gmail's mantra "archive, don't delete"; the capacity for infinite undo, terabyte-scale drives retaining every state of every file for the lifetime of their user; Bell's omnivorous MyLifeBits, explicitly conceived as a "fulfillment" of the idea of the Memex.[48] This is a sea-change in the production and recording of human knowledge, one whose implications go far beyond the hard disk drive as a technology of writing and inscription alone. As Derrida notes in Archive Fever, "what is no longer archived in the same way is no longer lived in the same way" (18).[49] Consumer electronics devices such as the iPod and the TiVo, both based on hard drive technology, offer ready examples: these products have revolutionized the storage of digital music and digital video with appropriately far reaching effects for the music and television industries as well as individual users' listening and viewing habits: the personalized jukebox-style playlists of MP3s supplanting the artist's sequencing of tracks on an record album or CD for example, or the ability TiVo confers to screen out commercials,

mix shows together, and establish an individual viewing schedule.[50]

New subjectivities are also emerging. "You are your C" is the title of a net art project by Carlo Zanni dedicated to "electronic soul mirroring": when the project is accessed online, the contents of the viewer's hard drive are displayed on the screen as the standard Windows file tree, as though they were simply another component of the World Wide Web. "Eyes are no more the soul mirror of a person; on the contrary the computer or the hard disk are."[51] (The "C" of course refers to the conventional mapping for a hard drive mounted on a Windows file system -- the hard drive is the "C" drive, or, interestingly, the "see" drive; note also Zanni's play on soul/sole.) The project is straightforward enough, but the dialectic between screen and storage, reflections and reservoirs, is instructive; as Zanni notes, the fear of having one's private information exposed, made visible on the Web is an explicit dimension of the work: "It is an old hacker trick ...usually people were thinking that the visualization was available for all the web audience, in truth it was only available in local for your machine."[52] Mary Flanagan employs similar ideas in a digital art piece entitled [*Phage*].[53] [*Phage*], which she describes as a virus, uses fragments of old media files residing on the user's hard drive to enact a 3-D representation of the computer's subconscious (executed in VRML). Images are bitmapped to geometric solids, creating visual extrusions like Dalían phantasmagoria. Clearly for both Zanni and Flanagan, life on the screen manifests a sometimes uneasy relationship to the life on the disk.

This convergence of "life" and data storage was explored even earlier in fiction -- William Gibson's "Johnny Mnemonic" is an obvious example, as the protagonists wrestle with the problem of unlocking the data consigned to the neuromantic mule's wetware drive: "I had hundreds of megabytes stashed in my head on an idiot/savant basis, information I had no conscious access to.... I'm not cheap to begin with, but my overtime on storage is astronomical" (2).[54] The theme appears in more subtle form in Douglas Coupland's *Microserfs* (1995), which also offers a counterpoint to Gmail, Flickr, and Bernstein's calculus of storage costs above (typical consumer hard drives weighed in at around 1 gigabyte when the novel appeared):

> Susan was doing her biannual hard-drive cleanup, which is half chore/half fun -- going on a deleting frenzy, removing all those letters that once seemed so urgent, that now seem pointless, the shareware that infected your files

with mystery viruses and those applications that seemed groovy at the time.

Susan's own efforts did get me to do a brief cleanup of my own hard drive. I thought of Karla's equation of the body with the computer and memory storage and all of that, and I realized that human beings are loaded with germs and viruses, just like a highly packed Quadra ...I posted a question on the Net, asking bioheads out there what lurks inside the human hard drive. (178)[55]

Or to take one final instance: "[Y]ou are the sum total of your data. No man escapes that," says Don Delillo in the voice of a government technocrat in *White Noise* (141).[56] While superficially compatible with Gordon Bell's statements, these literary examples all complicate the ambitions of a project of MyLifeBits, whose rhetoric at times is disarmingly literal. A Power-Point presentation available on the project's Web site, for example, shows Bell dissolving into a pixilated representation of himself, with the caption "I am data" (emphasis in original).[57] Double helixes and other thoughts in the post-human vein notwithstanding, there is also something almost willfully naïve about Bell's claims and ambitions -- do we really believe we are simply the sum total of all of the media we produce and consume? ("But where does the outside commence?" asks Derrida in Archive Fever; "This question is the question of the archive. There are undoubtedly no others [8].") The real question, it seems to me, is not whether we will have the storage capacity to accumulate copies every book, film, song, conversation, email, etc. that we amass in a lifetime (yes, probably, eventually) but how do these accumulations, these massive drifts of data, interact with irreducible reality of lived experience? A project such as Zanni's achieves part of its effect, I would argue, through its shock value: not only in putatively displaying one's private information to the world -- it doesn't, really -- but in holding up the mirror and allowing the user to see, objectively and decontextualized, the entirety of what he or she has accumulated on their hard drive. The work depends precisely *not* on the simple equation of the user with their data, but on the *proposition* that *if* you were equated with your data, *this* is what (and who) you would be. In other words, for the work to have its real impact the user must retain some sense of self apart from their data, some subjective reserve that says in effect, *no, there must be more to me than this*. Delillo is making this very same point by way of Jack Gladney's tribulations in the second half of the novel, all of

which come about through the friction of his escape velocity from the gravitational bands of his data. Such awareness is lacking in MyLifeBits, where the algebraic equation of life with data is treated as simple and self-evident.

Part of what enables the myth (or the meme) is the slippage between media convergence and total recall. The opening of the Power-Point mentioned above, for example, features a short animation depicting a messy array of media forms -- papers, telephone, file cabinets, music CDs, computer software -- all collapsing into a single blip on a hard drive.[58] Skyrocketing storage capacities are complemented, even *motivated*, by the putative flattening out of all media as homogeneous ones and zeros. Nicholas Negroponte supplies the classic formulation: "[B]its commingle effortlessly. They start to get mixed up and can be used or reused together or separately. The mixing of audio, video, and data is called *multimedia*; it sounds complicated but is nothing more than commingled bits" (18).[59] Friedrich Kittler is even more succinct: "The general digitization of channels and informations erases the differences among individual media" (1).[60] This essay has worked to discover the *heterogeneity* of digital inscription to the furthest extent possible, indeed to the nanoscale where, with the aid of a magnetic force microscope, individual bits take on their own weight and heft (like snowflakes, no two are quite alike). Even without the aid of such exotic instrumentation, however, the non-virtual realities of our contemporary media ecology should lead us to question the homogenizing myth of convergence. All media are bound to the materialities of their particular forms whose shifting contours resist any attempts to flatten through the mere rhetorical invocation of those homogenous ones and zeroes—ask anyone who has ever tried to navigate the shoals of region-specific DVD codes.[61] To put the matter even more bluntly, what happens when the titanic ambition of my desire to save a copy of every song I've ever listened to collides with the iceberg of DRM?[62]

This is also where the grammatology of the hard drive itself, as an inscription engine, comes into focus. Recall that we have a machine that "writes" without physical contact, which leaves no visible trace apparent to the unaided eye, and whose textuality consists in analog phenomena as detected, interpreted, and converted by stochastic processes before they assume a digital-symbolic value in a system's short-term memory. Computers, as Danny Hillis reminds us, are machines that carefully sustain their illusion of immateriality: "the implementation technology must produce perfect outputs from imperfect inputs, nipping small errors in the

bud. This is the essence of digital technology, which restores signals to near perfection at every stage" (18).[63] The reality is that hard drives make errors all the time; any drive that did not would be operating at such low data densities and speeds as to be unmarketable. Every sector of data on the disk includes error correcting codes derived according to established algorithms; the basic idea is that the mathematics generates a bit sequence that serves as a redundant expression of the original data (this is called hashing). If the two fail to match up during a read or write task then an error is indicated and the task is repeated. Users never see such errors, which are detected and corrected in the space of milliseconds, and this contributes to the way in which the drive is perceived as an abstraction identified only by a letter ("C") or a crude desktop icon. Absent are the range of small, localized glitches characteristic of other media -- the typo in the newspaper, the scratch on the vinyl record, snow on the TV channel -- that remind us of their mundane materiality. Our word processor may crash, but we don't open the document we were working on yesterday to find that certain characters have been transposed or left behind in the transition from screen to disk and back again. While it is just this kind of behavior that is often cited as evidence of digital media's putative immateriality, the hard drive's error-free performance is in fact the laborious and artificially achieved end product of decades of computer science and engineering. Projects such as MyLifeBits ultimately trade on the illusion of immateriality created by this engineering to drive their rhetorical claims.

There is a fiction then that computing is all about numbers, especially ones and zeros. But computing is really all about storage. Data cannot subsist without material representation. Given this, the history and technology of storage should be a prime locus of inquiry for anyone interested in computing from the standpoint of technologies of writing, textuality, and inscription -- in short, the stuff of representations. This essay has attempted to open that field for inquiry, something which I think will become even more vital as storage technologies themselves become more and more of an abstraction, more and more of a literal black box. By contrast, early RAMAC disk arrays were often proudly displayed: at the United Airlines terminal at Stapelton Field in Denver visitors were encouraged to view the machine as it recorded and retrieved their reservations in a specially designed glass-walled room -- the actress Eva Gabor was reportedly fascinated by the spinning platters.[64] But when personal computers began adopting them, hard drives were placed inside the case, and are now further dematerializing as a consequence of their soaring capacities.[65] In essence

you'll never "see" storage in that you'll never encounter your data in its entirety, in a format akin to the tree views we now take for granted (that which "You Are Your C" exploits). Instead you will filter, mine, search, retrieve. This is the key to Gmail, with its wedding of Google's search algorithm to your inbox and now too, if you like, your desktop (I'll pass). Gmail's labels and stars which allow the user to recreate traditional folders for their mail already seem vestigial and half-realized, the weakest portion of the whole concept. As data mining and pattern recognition technology improves and becomes ubiquitous, discrete folders will seem as antiquated and forlorn as yesterday's manila. The kind of serendipitous discovery of old files and applications recounted in *Microserfs* will become a function of the fluke search result, not manual tidying.

Storage is the spirit of our age. A recent article in the *New York Times* reports that all 90,000 volumes in the undergraduate library at the University of Texas at Austin are about to be removed to an off-site location, where they will be available for recall and retrieval.[66] Other colleges and universities are following suit. You can almost see the von Neumann architecture being concretized at the macro-level as the bricks and mortar of the library building -- the central processing unit -- are re-engineered to house a state of the art media and information center, packed with computers themselves packed with state of the art disk arrays and hard drive clusters. The books meanwhile, the random access devices of old, are being placed -- recursively it would seem -- in *storage*, shunted away to a remote locale where they will be available upon request. At a moment when we would clearly not be wrong to speak of storage as a cultural condition -- a storage generation or storage fever -- the hard drive is not the only relevant technology.[67] But I have attempted to articulate its grammatology here by making visible some of its strange mechanism, both beautiful and extreme.

Notes

[1] I would like to thank Lisa Gitelman, Katie King, Kari Kraus, and Nick Montfort for their excellent comments on various drafts of this article. I am also grateful to Professors Romel Gomez and Isaak Mayergoyz of the Department of Electrical and Computer Engineering at the University of Maryland for discussing their work on magnetic media with me, and accommodating a visit to their lab. The material in this essay is a condensed version of a longer section of my book, *Mechanisms,* forthcoming from the MIT Press. *Mechanisms* is concerned with the textual and technical primitives of electronic writing, chiefly erasability, variability, repeatability, and survivability. The epigraph from da Vinci, above, was located in Brian Armstrong-Hélouvry, Control of Machines with Friction (Boston: Kluwer Academic Publishers, 1991), 1.

[2] Simson L. Garfinkel and Abhi Shelat, "Remembrance of Data Past: A Study of Disk Sanitization Practices." IEEE Security and Privacy (January-February 2003): 17-27.

[3] See Frierich A. Kittler, Discourse Networks 1800/1900, trans. Michael Metteer (Stanford: Stanford University Press, 1990), Gramophone, Film, Typewriter, trans. Geoffrey Winthrop-Young and Michael Wutz (Stanford: Stanford University Press, 1999), Lisa Gitelman, Scripts, Grooves, and Writing Machines: Representing Technology in the Edison Era (Stanford: Stanford UP, 1999), Gitelman and Geoffrey R. Pingree, eds., New Media 1740-1915 (Camrbridge: MIT Press, 2003), Patricia Crain, The Story of A: The Alphabetization of America from The New England Primer to The Scarlet Letter (Stanford: Stanford University Press, 2000) and Adrian Johns, The Nature of the Book: Print and Knowledge in the Making (Chicago and London: University of Chicago Press, 1998). Also the essays in Timothy Lenior, ed., Inscribing Science: Scientific Texts and the Materiality of Communication (Stanford: Stanford University Press, 1998); and Bruce Clarke and Linda Dalrymple Henderson, eds., From Energy to Information: Representation in Science, Technology, Art, and Literature (Stanford: Stanford University Press, 2002). And the essays in *Language Machines: Technologies of Literary and Cultural Representation*, eds. Jeffrey Masten, Peter Stallybrass, and Nancy J. Vickers (New York and London: Routledge, 1999).

[4] The technical term that best captures the irreducible materiality of magnetic media is hysteresis, defined by Webster's Seventh New Collegiate as "a retardation of the effect when the forces acting upon a body are changed (as if from viscosity or internal friction); esp: a lagging in the values of resulting magnetization in a magnetic material (as iron) due to a changing magnetizing force." See http://www.lassp.cornell.edu/sethna/hysteresis/WhatIsHysteresis.html.

[5] Open the sealed case of a modern hard drive and even an untrained observer will note the resemblance to a small turntable, complete with platter(s) and spindle arm. This visual coincidence harbors deeper correlates. Like the phonograph, magnetic recording was originally intended to preserve sound, specifically speech. Moreover, magnetic recording emerged at almost precisely the same historical moment as Edison's phonograph: the American inventor Oberlin Smith articulated the essential principles in 1878 (a year after the phonograph debuted), and in fact corresponded briefly with Edison; Smith, however, never actually built a recording device. That was left to the Danish researcher Valdemar Poulson, who in 1898 captured the first magnetic recording on a length of steel wire. Poulson immediately set about developing a machine he called the telephonograph, which would allow people record and store a telephone conversation—in effect an answering machine. The telephonograph was never to be a commercial success (Poulsen's successor, the American Telephonograph company, tried to compete with Edison's phonograph for the market in dictation machines), but the basic principles of magnetic recording had been established. The next major advances came in the 1930s when several German firms, including BASF, introduced magnetic coated tape (first paper and then plastic) as well as a dependable recording apparatus (and made additional advances, including High Bias recording). The magnetophone, as magnetic tape machines were then called, was to prove an important tool for the emerging Nazi regime as well as the war-time German military. After the war the technology quickly migrated to the rest of Europe and the United States. With magnetic audio recording commercially launched it was not surprising that the nascent computer industry began exploring magnetic recording solutions for its increasingly storage-dependant products. For more on the early history of magnetic recording, see Eric D. Daniel, C. Denis Mee, and Mark H. Clark, *Magnetic Recording: The First One Hundred Years* (New York: IEEE Press, 1999), particularly chapters 2-5.

[6] One recent exception appears to be an issue of the journal *Mediamatric* on "Storage Mania" edited by Geert Lovink, under the sign of Kittler: http://www.mediamatic.net/article-200.5944.html. The history of computer storage media has also been well chronicled in corporate histories of the computer industry. See Charles J. Bashe, Lyle R. Johnson, John H. Palmer, and Emerson W. Pugh, *IBM's Early Computers* (Cambridge: MIT Press, 1986), and Edmund W. Pugh, Lyle R. Johnson, and John H. Palmer, *IBM's 360 and Early 370 Systems* (Cambridge: MIT Press, 1991).

[7] Error or global failure is often precisely what brings the drive's materiality into focus, however, sometimes in bracing and unexpected ways. A graduate student of mine offers the following story: "On Tuesday my computer crashed, apparently non-recoverably, taking with it my final (due the next day) and my syl-

labus. Everything else was backed up due to a recent Windows reinstall, but the loss of the final was pretty critical. I took it down to a computer pro friend who had cooked up some ways of hopefully fixing the problem or bypassing it long enough to get the files, but it turned out that the problem was that the hard drive wasn't spinning up in the first place. If it wouldn't spin up, he couldn't even do the recovery stuff he had planned. I was sick (on top of!) so I left it with him and went to get some sleep so I could start reconstructing the paper in the morning. He had the files to me by noon the next day. Here is what he did: took out the hard drive, put it in a ziploc, and stuck it in the freezer overnight. The metal contracts, and when you take it back out, it expands at different rates (for the different types of metal), allowing stuck bearings to come unstuck and non-spinning heads to spin up one last time. *This is the coolest thing I have ever heard*" (emphases in original). My thanks to Jess Henig for sharing this, which may well indeed be the coolest thing I have ever heard as well. Personal email to the author, August 20, 2004, 12:28 PM.

[8] For Hayles's essay, see *Electronic Culture: Technology and Visual Representation,* ed. Timothy Druckrey (Romford, England: Aperture, 1996): 259-277. It originally appeared in October 66 (Fall 1993): 69-91. "[T]he simple, and possibly profound, truth," writes Xerox document scientist David Levy, "is that you can't see bits. You can't see them, you can't hear them, you can't touch or smell them. They are completely inaccessible to the human senses" (138). Jay David Bolter puts it this way: "If you hold a magnetic or optical disk up to the light, you will not see text at all. At best you will see the circular tracks into which the data is organized, and these tracks mean nothing to the human eye" (42).

[9] Nick Montfort, "Continuous Paper: The Early Materiality and Workings of Electronic Literature": <http://nickm.com/writing/essays/continuous_paper_mla.html>.

[10] My account of "Professor RAMAC" is heavily indebted to Mitchell E. Morris's historical article on the subject, "Professor RAMAC's Tenure," published in the industry magazine *Datamation* (April 1981): 195-8. I would like to acknowledge Paul E. Ceruzzi's *A History of Modern Computing* (Cambridge: MIT Press, 1998) for the initial citation to Morris.

[11] IBM's first corporate client took delivery on a RAMAC in June, 1956—ironically it was the Zellerbach Paper Company in San Francisco.

[12] <http://www-03.ibm.com/ibm/history/exhibits/650/650_pr2.html.>

[13] And this was prefigured by earlier advances in storage. In the case of the UNIVAC, its revolutionary character was manifest to the end user less in its implementation of the stored program concept or the speed of its processor than, as Ceruzzi notes, in its magnetic tape storage system: "To the extent that its customers perceived the UNIVAC as an 'electronic brain' it was because it 'knew'

where to find the desired data on a tape, could wind or rewind the tape to that place, and could extract (or record) data automatically" (30).

[14] See *The Language of New Media* (Cambridge: MIT Press, 2001).

[15] Paul N. Edwards, in chapter 3 of his important The Closed World: *Computers and the Politics of Discourse in Cold War America* (Cambridge: MIT Press, 1996) argues that the Air Force's billion-dollar SAGE air defense network (developed and deployed from 1954-1961) was the first real-time computer system, hence the birth of interactive computing. SAGE was certainly the first real-time distributed computer system, and not coincidentally, was instrumental in refining the performance of magnetic core memories, then the primary alternative to magnetic disk for random access storage. Moreover, SAGE operators used light pens to plot aircraft movements on the cathode ray tubes that were the first implementation of a real-time screen display. SAGE's significance to the history of both hardware and software cannot be overstated; as Edwards documents in detail, the demands of a real-time command and control network definitively tipped the balance of government funding in favor of digital over analog computation. See also Paul E. Ceruzzi, *A History of Modern Computing* (Cambridge: MIT Press, 1998), 49-53, and for a discussion of the importance of SAGE to the history of software Martin Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog: A History of the Software Industry* (Cambridge: MIT Press, 2003), 36-41. I would argue, however, that Edwards overlooks the simultaneous importance of the demand for inventory and production control solutions in both the military and commercial sectors as a catalyst for real-time computing, expressed in particular through IBM's development and marketing of the RAMAC.

[16] Morris, "Professor RAMAC's Tenure," 198.

[17] English, French, Italian, Dutch, Spanish, Swedish, Portuguese, German, and Russian. That these were also all *alphabetic* languages compatible with the rudimentary text processing technology of the day reinforces rather than diminishes the point.

[18] The Professor is probably even more aptly described as an ancestor to systems like BASEBALL, an "automatic question answerer" from the early 1960s that was capable of offering up vast stores of baseball trivia. See Nick Montfort, *Twisty Little Passages: An Approach to Interactive Fiction* (Cambridge: MIT Press, 2004): 81.

[19] Jacob Rabinow, "The Notched-Disk Memory," *Electrical Engineering* (August 1952): 745-9.

[20] Terry Belanger of the University of Virginia Rare Book School informs me of the following: "In the RBS collections is a 'book,' which consists of a 1/4" stack of 2" paper disks, with a spiral binding around the entire circumference (with the result that the book cannot be opened). Its 'titlepage' (the top disk) has a single

word on it: 'unbound.'" Personal email Wed, 10 Sep 2003 14:07:07 –0400.

[21] I'm thinking here of Jeffrey Sconce's Haunted Media: Electronic Presence from Telegraphy to Television (Duke UP, 2000) and Avital Ronell's *The Telephone Book: Technology -- Schizophrenia -- Electric Speech* (U of Nebraska P, 1989). See also Gitelman (1999) and Kittler (1999) for discussions of automatic writing.

[22] Johnson would later remark: "...I would be free to choose projects to work on. One half of my projects were to be new products and one-half were to be devices in support of customers' special engineering needs. No projects were to be duplicates of work in progress at other IBM laboratories. The laboratory was to be dedicated to innovation." Quoted in Eric D. Daniel, C. Denis Mee, and Mark H. Clark, *Magnetic Recording: The First One Hundred Years* (New York: IEEE Press, 1999), 273.

[23] Quoted in Bashe, Johnson, Palmer, and Pugh, IBM's *Early Computers*, 231.

[24] Brian Hayes, "Terabyte Territory." American Scientist 90 (May-June): 212-6. Hayes adds that the paint was first filtered through a silk stocking and then "poured onto the spinning disk from a Dixie cup" (212).

[25] For more discussion on the development of the hard drive at the San Jose lab and its significance for contemporary discussions of electronic textuality, see my forthcoming book, *Mechanisms*.

[26] These are, of course, what are generally accepted as the first messages or recordings for the telegraph, the phonograph, and the telephone, respectively. The first email message was sent by Ray Tomlinson in 1971; it bears the distinctive markings of another writing technology: "QWERTYUIOP." The hard drive's "This has been a day of solid achievement" is documented in Reynold B. Johnson's after-dinner talk to the DataStorage '89 Conference, September 19, 1989, San Jose, California: <http://www.mdhc.scu.edu/100th/reyjohnson.htm>. Bashe, et al. corroborate this as the date for the first successful read/write operation, but do not provide the text of the message (287).

[27] We do often speak of *putting* a file on a disk. Likewise, "saving to" and "saving on" a disk appear to be used with about equal frequency. Since it is clear that we can thereby conceive of disks or other storage media as a form of material support for data, it becomes all the more conspicuous that we only seldom speak of writing a file on a disk. I would argue that writing implies a level visual feedback that is generally absent from electronic storage media, obtaining instead at the level of the screen or other output device -- architecturally distinct components of the von Neumann model. The OED helps chart this lexical unease: in the 1940s, one could comfortably say either write "on" or write "to" tape or disk (or indeed, more commonly, write "into"). Since the 1950s, however, the preferred locution has been simply "to."

[28] I want to make explicit my debt to one resource in particular in the section that follows, the online PC Guide, written and maintained by Charles M. Kozierok, which offers by far the most detailed non-specialist's discussion I know of the components and operation of a hard disk drive: <http://www.pcguide.com>. I have benefited a great deal from Mr. Kozierok's expertise, and that knowledge is applied throughout this section. Readers interested in further exploring the topics presented here are strongly encouraged to visit his site.

[29] See <http://www.boingboing.net/2005/03/08/bookshaped_hard_driv.html>.

[30] In point of fact, read and write heads are no longer the same entity. The development of first magnetoresistive heads and then giant magnetoresistive heads—in 1991 and 1997 respectively -- engendered the creation of a separate read head, based on the principle of substances whose electrical resistance changes in the presence of a magnetic field. The introduction of magnetoresitive heads led to dramatic increases in aerial density (Hayes 214-5).

[31] Pioneered in the late 1980s, Magnetic Force Microscopy (MFM) is currently the state of the art for imaging data representations recorded on magnetic media. Its primary application is not data recovery but industrial research and development: MFM studies are an integral part of evaluating laboratory advances in magnetic recording. MFM is actually an umbrella-term for several closely related procedures and technologies all based on the scanning tunneling microscope (STM, a variety of "electron microscope"), and it in turn offers only one of several known methods for imaging magnetic phenomena. Prior to MFM, samples of magnetic recording media were imaged by treating them with a ferrofluid, a liquid magnetic suspension that produced patterns visible under an optical microscope. Today MFM is being supplemented by a newer technique called spin-stand imaging. On November 14, 2003, I visited Professor Romel Gomez at the University of Maryland's Laboratory for Applied Physics, where I observed a Digital Instruments (now Veeco) Magnetic Force Microscope in action. The device is recognizable as a microscope, with familiar elements such as a stage and ocular tubes. Three monitors provide views: one shows an optical magnification of the surface of the sample, the second displays instrumentation and settings, the third displays reconstructed images, both AFM and MFM. The process is time and labor intensive: acquisition rates are hover around 1 bit (not byte) per second, and the surface area of a sample are small -- perhaps five square millimeters. If we do the math -- eight bits in a byte -- we can see that we might, assuming optimal conditions, be able to image seven or eight bytes per minute. A single 512 byte sector would require well over an hour to image completely. A relatively modest ten kilobyte text file would require 24 hours of continuous imaging under optimal conditions. A 1 MB media file would take months. Though recoveries of complete files are theoretically possible (through what is known in the trade as "heroic efforts") the process

would be extremely painstaking and requires weeks or many months.

[32] Some readers may suggest that a book is only incidentally volumetric, since more pages can always be added to accommodate additional content. This is true in a very generic sense, but students of printing history and bibliography will know that counter-examples are everywhere once one gets down to the shop floor: in the hand-press period, for example, compositors were known to have changed the spelling of words to make them conform to the length of a line. Nearly all mass-produced books are printed in signatures, very large pages that are then cut and folded into individual leaves. Authors are often asked to add or remove content so as to bring their raw page counts into alignment with the multiples of a signature. Word processing and desktop publishing software, meanwhile, typically offers a "Make It Fit" feature that will take a few stray words alone at the end of a document and format them on the preceding page. These quick examples, from early modern to contemporary publishing, indicate that the codex is volumetric in all three of its dimensions, length, breadth, and depth.

[33] This is a simplification. FAT is actually a family of technologies, and the actual implementations include FAT12, FAT16, FAT32, and VFAT. On more recent systems such as Windows 2000 and XP, FAT is replaced by a technology known as NTFS. And, of course, neither UNIX nor Macintosh computers use FAT all; they have their own file system technologies.

[34] It is well known that "deleting" a file does not actually remove it from the disk, even after emptying the so-called Recycle Bin. Instead, in keeping with the volumetric nature of disk storage, the delete command simply tells the FAT to make the clusters associated with a given file available again for future use—a special hex character (E5h) is affixed to the beginning of the file name, but the data itself stays intact on the platter. File recovery utilities work by removing the special character and restoring files to the FAT as allocated clusters; more advanced forensics techniques are sometimes capable of deeper recoveries, even after the clusters have been rewritten. Computer forensics forms one major axis of my approach in *Mechanisms*, where I discuss in detail its relationship to questions of materiality, textuality, and the technology of writing.

[35] For a good discussion of the codex as a random access device (by way of comparison to the linear scroll), see Jeffrey Masten, Peter Stallybrass, and Nancy J. Vickers in their editors' introduction to *Language Machines: Technologies of Liteary and Cultural Production* (Routledge 1997): 1-14.

[36] The speed at which the disk rotates around the spindle remains one of the critical bottlenecks in hard drive development. At least one British firm, Dataslide, is experimenting with using vibration instead of the disk's spinning motion to generate the movement necessary for read/write heads to detect magnetic fluctuation changes. See <http://www.dataslide.com>, particularly the articles listed in

the "News" section.

[37] I am grateful to Kari Kraus for suggesting "planographic" as one of the hard drive's grammatological primitives.

[38] For a general discussion of the stability of magnetic storage media and factors affecting its deterioration, see Bryan Bergeron, *Dark Ages II: When the Digital Data Die* (Upper Saddle River, New Jersey: Prentice Hall, 2002), 78-83. As might be expected, there not yet consensus on the matter.

[39] The canonical technical discussion remains Peter Gutmann's "Secure Deletion of Data from Magnetic and Solid-State Memory": <http://www.cs.auckland.ac.nz/~pgut001/pubs/secure_del.html>.

[40] This language comes from the US Department of Defense's "Clearing and Sanitization Matrix," a copy of which is available here: http://www.hipaadvisory.com/tech/disksan.htm. I discuss questions of deleting and recovering data from magenetic media further in my forthcoming book, *Mechanisms*.

[41] The firm is Convar, <http:/www.convar.com>. Further information is available in their press materials.

[42] Wierner's exact prescription, from *Cybernetics* (1948) was as follows: "That the machine contain an apparatus for the storage of data which should record them quickly, hold them firmly until erasure, read them quickly, erase them quickly, and then be available immediately for the storage of new material" (4).

[43] For an overview of the current state of the art, see Margaret Quan, "Holographic storage nears debut," EE Times, April 26, 2001: <http://www.eetimes.com/story/OEG20010423S0113>.

[44] <http://markbernstein.org/Apr0401/ThrowingStuffOutisObsolete.html>.

[45] Lesk, "How Much Storage is Enough?" Storage 1.4 (June 2003): <http://www.acmqueue.org/modules.php?name=Content&pa=showpage&pid=45>.

[46] See Hayes, 215; and "A Conversation with Jim Gray," Storage 1.4 (June 2003): <http://www.acmqueue.org/modules.php?name=Content&pa=printer_friendly&pid=43&page=1>.

[47] See <http://research.microsoft.com/barc/mediapresence/MyLifeBits.aspx>.

[48] See, for example, Gemmell, et al. "MyLifeBits: Fulfilling the Memex Vision": <http://research.microsoft.com/barc/mediapresence/MyLifeBits.aspx>.

[49] Jacques Derrida, *Archive Fever: A Freudian Impression*, trans. Eric Prenowitz (Chicago: U of Chicago P, 1995).

[50] Adam Porter, a Philadelphia DJ, now makes his living by renting out iPods he fills with customized playlists for restaurants and other clients: <http://citypaper.net/articles/2003-06-12/music.shtml>. For many, however, the iPod has come to function more as a generic storage device than a music player; so much so that the UK Ministry of Defense (and an increasing number of private corporations) has deemed them a security risk for their ability to facilitate the rapid transfer of very

large volumes of data. See http://www.consolationchamps.com/archives/001142.html. Cases of identity theft in which iPods figure prominently are also on the rise.

[51] Artist's statement online at Rhizome.org Artbase.

[52] Personal email from Zanni to author, 8 Jan 2005 19:47:53 +0100.

[53] [Phage] can be found here: <http://www.maryflanagan.com/virus.htm>.

[54] In Gibson's collection *Burning Chrome* (New York: Ace, 1986).

[55] *Microserfs* (New York: HarperCollins, 1995). See also the following dialog, spoken by Karla: "Bodies are like diskettes with tags. You click on them and you can see the size and type of file immediately. On people, this labeling occurs on the face" (205).

[56] *White Noise*, Viking Critical Library, ed. Mark Osteen (New York: Penguin, 1984, 1998).

[57] See "Jim Gemmell's MyLifeBits talk," February 2004: <http://research.microsoft.com/barc/mediapresence/MyLifeBits.aspx. Slide 5>.

[58] Slide 1.

[59] Nicholas Negroponte, *Being Digital* (Cambridge: MIT Press, 1995).

[60] See *Gramophone, Film, Typewriter*, trans. Geoffrey Winthrop-Young and Michael Wutz (Stanford: Stanford University Press, 1999).

[61] For related work on this theme, see Matthew G. Kirschenbaum, "The Word as Image in an Age of Digital Reproduction" in *Eloquent Images: Word and Image in the Age of New Media*, eds. Mary E. Hocks and Michelle R. Kendrick (Cambridge: MIT Press, 2003): 137-56 and Kirschenbaum, "Virtuality and VRML: Software Studies After Manovich": <http://www.electronicbookreview.com>.

[62] In conversation with me, MyLifeBits' Jim Gemmell suggested that the solution might ultimately be to record metadata about a particular song, and then rely on digital services to retrieve an appropriately licensed copy of the actual music if the user really desired to listen to it. Such a solution only underscores the point about the social and economic materiality of data, and the ways it will resist universal storage.

[63] Hillis, *The Pattern on the Stone* (New York: Basic Books, 1998).

[64] Morris, 196.

[65] While it is true that devices like iPods and portable USB hard drives have also made storage visible and tangible by liberating the drive apparatus from the case, the vulnerabilities of hard drives in mobile devices is well known. As of this writing, Apple has just released its first Flash memory-based iPods; as Flash memory devices continue to proliferate and improve they will compete for the portable market and perhaps force hard drives back inside the protective environs of the case. Something of this is perhaps captured in a Web page that instructs readers in how to turn their old hard drives into wind chimes: <http://halogen.note.

amherst.edu/~wing/wingie/tech/hdchime/hdchime.php>.

[66] Ralph Blumenthal, "College Libraries Set Aside Books in a Digital Age." *New York Times*, May 14, 2005.

[67] Steve Johnson, in *Everything is Bad is Good For You* (New York: Riverhead Books, 2005) offhandedly refers to the "infinite storage" of eBay (196). He is, of course, exactly right. eBay is a globally distributed, emergent storage system for material goods and artifacts.

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