Guidelines for Contributors

November 2022 edition

Title: Working titles under consideration are *Redefining Digitality*; *Defining Digitalities*; or simply *What's Digital?*

Editors: Thomas Haigh, Sebastian Gießmann and Valerie Schafer

Concept of the Book: Over the last decade or so, *digital* has replaced *information* as shorthand for the defining characteristic of our technological era. In the subtitles of their respective books, Walter Isaacson celebrates the hackers and geniuses who created a *digital revolution*, George Dyson argued for Princeton as a "point source" for the *digital universe* and David Gugerli framed the adoption of computer technology as *the emergence of digital reality*. In the business world, SAP has branded the adoption of its latest products as a *digital transformation*. Taiwan has a *digital minister*. Removing the optical disk drive from the PS 5 console created a *digital edition*. Academic centers study *digital cultures* and *digital citizenship*, preserve *digital heritage* or practice the *digital humanities*.

These invocations of digitality are rarely accompanied by any definition of what digitality signifies in that context. The word is often used as if it had a clear, technical meaning inherited from its origins in engineering practice. Yet the *digital* in *digital cultures* is clearly not the same as the *digital* in *digital counter*. What, one might ask, is digital about digital cultures? What is digital about the digital humanities? Or, for that matter, digital media or digital communication? And what do any of those things have to do with digits?

Authors such as Matthew Kirschenbaum, Paul Dourish, and Jean-François Blanchette have written exemplary studies of digital materiality but aside from an ongoing book project by Ron Kline we know of no sustained historical exploration of the origin of the concept of digitality or the complexities of its divergent careers. Our book is an attempt to historicize digitality.

Title: All chapter titles take the form of a question that begins with "What's Digital About." Your essay should provide a clear answer to that question. That means probing what digitality has been taken to mean in one or another context, who (explicitly or implicitly) defined it that way, what hidden interests or assumptions this reveals, etc.

Length: Around 5,000 words including notes (but not bibliography).

Style: Your contribution should be a lively, boldly written essay. Traditional edited volumes are pretty much dead, so for this book to work we need shorter pieces with big topics, clear points of view, and interesting claims. In recent years the books *Digital Keywords* (Princeton, 2016), *Media Technologies* (MIT, 2014) and *Your Computer is On Fire* (MIT 2021) have beaten the odds to find broad readerships with variations on this approach. We need to be able to present the book as something similar.

Two things that will not work in this context are detailed archivally based historical narratives and literature reviews. Historical rigor is what's going to set this book apart. But extract key points, pick telling details, and use them to build an argument with. You can still publish the long, detailed narrative in a journal AND use some of the same material here in a different way. We will be having citations and notes, but this is not a "handbook" volume and your contribution should not be an exhaustive review of the literature.

From a disciplinary viewpoint, the book is balanced between history, media studies and STS. But we see its goal as improving our historical understanding of digitality. We want the book to be comprehensible to people who are not already deeply immersed in media or cultural theory. Explain any theoretical concepts you do rely on as clearly as possible for an audience assumed to be unfamiliar with their work. It follows that any given chapter has scope to introduce only a small number of theorists and frameworks, since the overhead of explaining the key ideas would otherwise fill all the available space. For the purposes of this book, we see theory as a means to the end of better explaining a specific aspect of digitality, rather than digitality as a venue in which to advance a particular understanding of theory.

Structure of the book

One of our objectives is to take seriously the potential of digitality as an analytical category. Most current discourse simply uses *digital* as a vague signifier for the clusters of networks, platforms, and media technologies that underpin ever more social and cultural practices. In contrast, we intend to rigorously explore the fundamental digital affordances central to the operation of modern computers from the 1940s onward. The digital computer has followed a remarkable trajectory (traced in Haigh's recent book *A New History of Modern Computing*) from a rare and highly specialized tool for scientific number crunching to, in the shape of a smartphone, a ubiquitous device used daily by most of the world's population for everything from watching movies to finding sexual partners. Even smartphones make up only a few percent of the total world population of computers, most of which are embedded in technologies from light bulbs to cars. Conventionally this exceptional trajectory is explained, if it is explained at all, with vague references to the universality of the Turing machine or the inexorable progression of Moore's Law. But what if we take seriously the *digitality* of the *digital computer*?

This does not mean surrendering to computer exceptionalism. By treating key affordances of modern computers as either inherited from earlier media practices (such as those used in punched chard machines and alphabets) or as depending on those practices we aim to deexceptionalize computer technology. The first part of the book therefore explores digitality as form of reading and writing information distinct from algorithmic control. We look instead at punched cards, music boxes, telegraphy, alphabets, hand gestures, and alphabets. This section also introduces the fundamental tension between the histories of digitality as an actor's category, introduced in the 1940s to distinguish between digital and analog computers*,* and digitality as an analytical category. Once digitality was invented, its proponents immediately claimed that technologies such as punched cards had been digital all along. The packet of sample chapters includes drafts of the first three chapters of this section: "What's Digital about Representing Numbers," "What's Digital about Digital Communication," and "What's Digital about Digital Media?" Other chapters are expected to focus on dance notation, weaving, Chinese script, and digital electronics.

The second section introduces the modern computer and its new capability of algorithmic control. The packet includes a draft of the first chapter of this section, "What's Digital About Algorithmic Control." Other chapters will explore the digitality of things including: data, layered abstractions, modularity, network packets, universal access, and telephony. A key objective in this section is to show how nested affordances of digitality, grounded in the fundamental digital practices of reading and writing, make possible the nested stacks of hardware and software technologies that define contemporary computing practice.

In the third section the focus of the book shifts to the proliferation of more fuzzily defined conceptions of digitality. The opening chapter, "What's Digital about Nicholas Negroponte" focuses on Negroponte's 1995 book *Being Digital* as an important and influential statement of two key themes of this discourse: the idea that digitality is about immaterial bits rather than material atoms, and the adoption of the digital revolution as rhetoric of technologically driven social and cultural change. Other chapters will ask what's digital about things such as: digital money, digital standards, digital heritage, digital architecture, the digital economy, digital government, and digital methods. Because the topics covered in this section are not as tightly coupled with the technical senses of digitality the authors of these chapters will be focusing more on rhetorical and cultural trajectories for these new concepts of digitality; however we do encourage them to make those connections where possible.

You may notice a certain vagueness about contributors here. We have a provisional list of chapters and authors who have previously expressed interest in being part of the book, but in some cases that enthusiasm was expressed a year ago and in all cases without having seen the introductory chapters for the relevant parts of the book. We do not want to name contributors until we have reconfirmed their interest given the specific format and timeline we've finished up adopting for the book. Suffice it to say that we are excited by the lineup of contributors who have expressed preliminary interest.

Timeline:

- 30 November 2022: Confirmation of participation and topic of contribution.
- (by end of 2022): Submission of proposal to MIT Press as our first choice publisher
- 20 March 2023: Receipt of draft essay
- 31 May 2023: Feedback from editors and fellow contributors
- 20 August 2023: Submission of revised essay
- September 2023: Submission of complete manuscript to press

1.1: What's Digital About Representing Numbers?

I will argue in this chapter that the study of digitality should begin with careful attention to digits.[1] Digits matter here in two ways. First, our current discourse of *the digital* has its historical roots in the categories of *digital* and *analog*, which were defined in the 1940s to distinguish between two approaches to automatic computation. Digital computers were digital because they carried out their mathematical operations by encoding and manipulating digits. Second, some of the crucial affordances of today's electronic digital media have their roots in the characterizes that digits exhibit whether manipulated by humans or by machines. Digits are discrete set of symbols that can be reliably transcribed from one medium to another and sequenced to represent quantities of any size or to any degree of accuracy.

Digital was, in its original context, a quite literal term confined to machines that represented numbers rather than other control systems based on discrete encodings such as automatic looms or musical boxes. It was not, however, confined to electronic digits or immaterial devices. While the categories of digital and analog were created in response to the emergence of electronic computation they were immediately understood as applicable to earlier technologies going all the way back to the abacus. The initial choice of the term *digital* and its eventual resurgence as shorthand for our current technological epoch were both somewhat arbitrary. Yet taking the continuity seriously can be illuminating. The essential affordances of modern digital technologies are built on top of core affordances of digitality shared not just with earlier kinds of digital machines but with digits themselves.

The literal digitality of machines that represent digits is distinct from a broader and later sense of digitality as the encoding of sequences of symbols. Digits are a subset of the alphanumeric characters manipulated automatically by computers from the 1950s onwards, and those symbols were used in turn to represent other things such as audio, video, and pictures. We will talk about the extension of the concept of digitality to include, as a kind of metaphor, these non-numerical capabilities in the next chapter.

Historical Origins of Digital and Analog

While digitality has recently been equated with immateriality, the antonym of *digital* is not *physical* but *analog*. As Ronald Kline has explained in his careful and exhaustively researched paper on the topic, the terms were introduced during the second world war as automatic computer projects began to proliferate.[2] Kline's earliest identified use of the words to distinguish between two classes of computer occurred in 1942, in a document by George Stibitz of AT&T's Bell Labs. During the war he worked with the National Defense Research Committee, a group chartered to bring scientific expertise to assist in the nation's struggle. Stibitz introduced the juxtaposition of analog and digital in a memo commenting on a set of proposals for the design of a computer able to direct anti-aircraft guns. That was a mathematical problem: the gun had to fire not at the plane's current position but at the point it would be when the

---

[1] By this I mean numerical digits, though others have argued for tracing the idea of digitality back through another layer of metaphor to explore correspondences between the capabilities of digital systems and human fingers. Benjamin Peters, "Digital", in *Digital Keywords: A Vocabulary of Information Society & Culture*, ed. Benjamin Peters (Princeton, NJ: Princeton University Press, 2016):93-108.

[2] Ronald R Kline, "Inventing an Analog Past and a Digital Future", in *Exploring the Early Digital*, ed. Thomas Haigh (Cham, Switzerland: Springer, 2019):19-39.

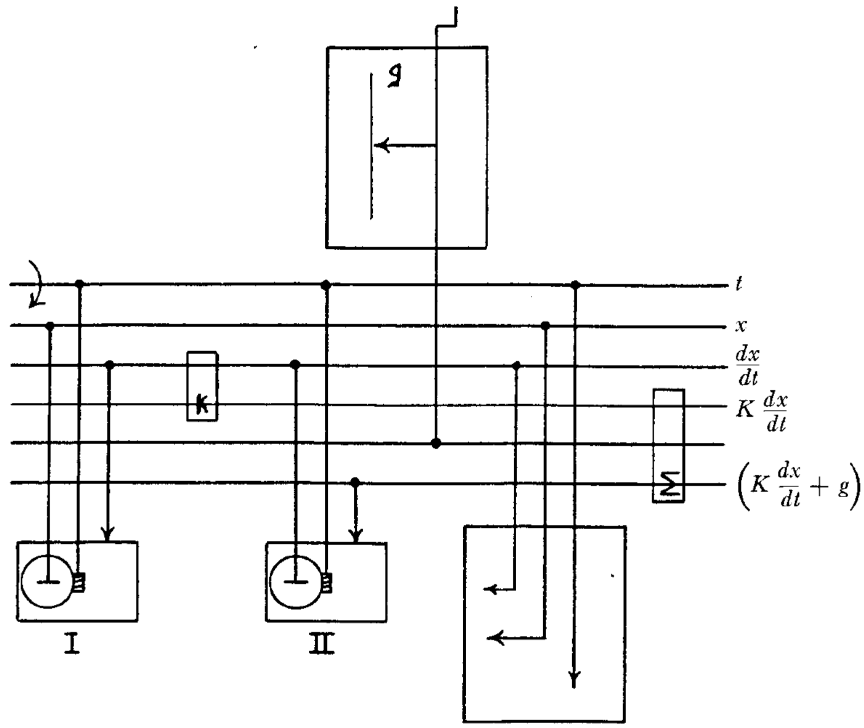
shell's arc intersected with its own future course. This required the rapid solution of differential equations.[3]

Stibitz is best remembered as the creator, between 1937 and 1946, of a series of computers that used electromechanical relays to represent numbers. These took the approach he designated as *digital*. Their relays switched automatically between two possible positions. A cluster of relays represented a number using the binary number system. Addition, multiplication, and other mathematical operations took place automatically as electrical impulses moved through wires but the arithmetic involved followed the same basic rules that a school child might have carried out using a pencil and paper (adjusted, of course, for the differences between binary and decimal – add 1 to 1 to get 0 carry 1, rather than add 1 to 9 to get 0 carry 1). The machines were *digital* because their mechanisms encoded digits and manipulated them to reach their solutions.

The other class of machines were called *analog* because their internal structure provided a model, or analogy, of the system being investigated. Kline suggests that this term slightly predated *digital* in this context, having been used since the 1930s. Vannevar Bush at MIT had investigated the behavior of power grids by building in the laboratory what were essentially scale models – each small wire and current proportional to the much heavier wires and larger currents flowing through the real power network. He followed this up with something more flexible and more abstract: the differential analyzer. Each of its six spinning disks represented one term in a differential equation. The disks were mounted on shafts, which span more rapidly as quantities they represented increased. The wheels sat vertically on top of the disks. Like the stylus of a record player they could be moved closer or further from the middle of the disk. The closer they got to the outer edge of a disk they more rapidly they rotated. Motion of a wheel was mechanically amplified to control the motion of the next disk. Adjustments, including the positioning of wheels and the use of gears to add together the motion of two shafts, changed the relationships between the six terms.[4]

[3] David A Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics* (Baltimore: Johns Hopkins University Press, 2002), ch. 9 & 11 provides an account of the NRDC's work in this area that foregrounds the role of Stibbitz and Shannon, and follows the legacy of this project into Stibbiz's general purpose relay computing projects.

[4] Larry Owens, "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer," *Technology and Culture* 27, no. 1 (January 1986):63-95. Vannevar Bush, "The Differential Analyzer. A New Machine for Solving Differential Equations," *Journal of the Franklin Institute* 212, no. 4 (October 1931):447-488.



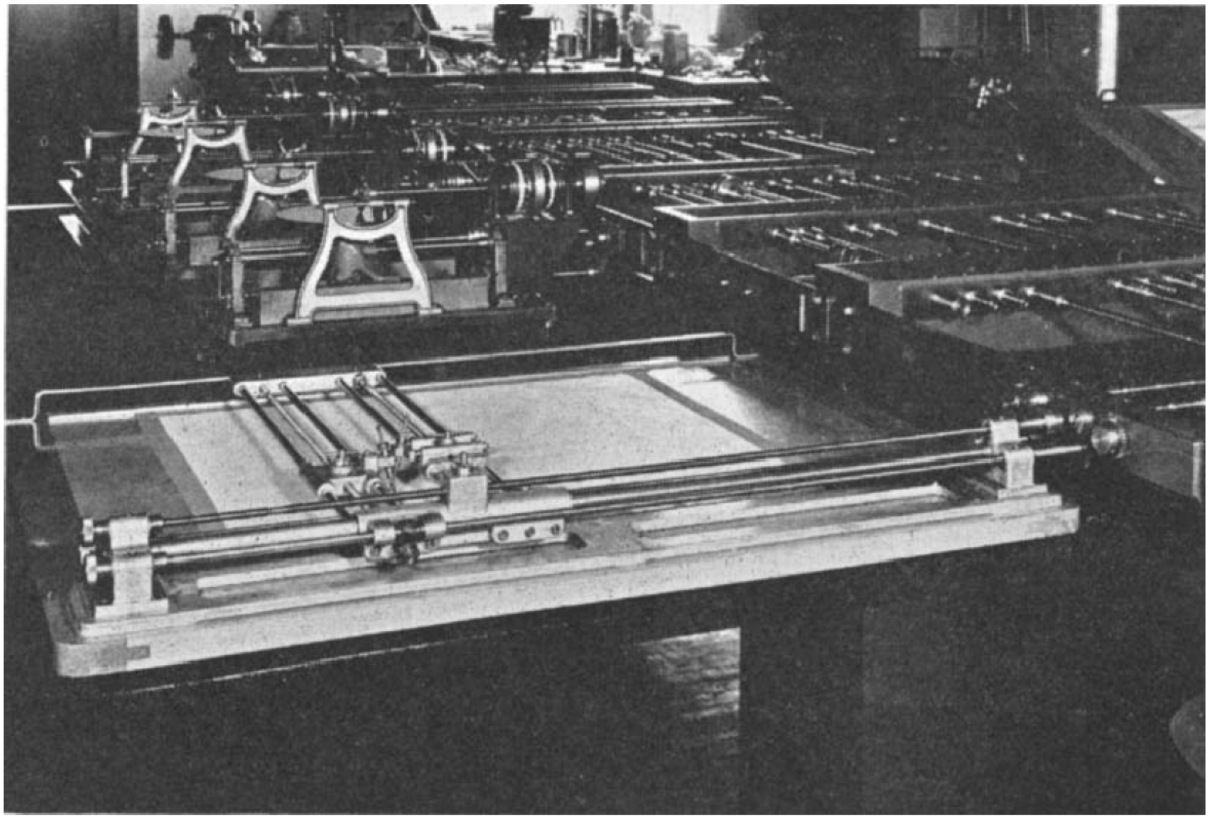
Analyzer connections for simple problem of falling body.

$$\frac{d^2x}{dt^2} + k\frac{dx}{dt} + g = 0.$$

Bush's paper describing the differential analyzer used this schematic notation to describe the relationship between each of the six shafts and the corresponding term in a mathematic equation describing the motion of a falling body. The diagram also specifies the relationships between shafts, implemented mechanically with devices such as integrators and gear boxes.[5]

Specific parts of the integrator were thus analogous to specific parts of the system being modelled. The integrator as a whole became an embodiment of the mathematical equation, an analogy with the entire system being modelled. *Allegory* might have been a better term than *analogy* for this complex correspondence. In an allegory, such as George Orwell's *Animal Farm* or a biblical parable, each part of the story corresponds with something specific in the larger world. The relationships between the different objects in the story are the same as those between the analogous features of the world. If the rotation of one disk in the differential analyzer represents the height of a shell, another its velocity, and a third its acceleration then the relationships between those disks should, when the device is properly adjusted, be very close to the relationships of those real-world quantities. There were no digits involved –operators controlled the speed of one or more of the disks by tracing input curves using devices coupled to the motion of wheels. At the far end of the machine, a mechanical arm sketched the shape of the result.

[5] Bush, "The Differential Analyzer. A New Machine for Solving Differential Equations", p. 457.



The output table, on which a pencil moved by the differential analyzer would draw a curve representing the solution to the problem traced on the input table.[6]

Differential analyzes were the most advanced automatic computers of the 1930s. Comparable principles were used in the gun director design chosen for the NRDC project, and had already been applied for comparable systems used for fire control on naval vessels. Analog computers were sold and developed into the 1970s. They used a range of media to represent changes in the quantities being computer. In some fluid dripped between tanks, in others variations in electrical current replaced the changes of rotational speed used in the differential analyzer. But the all the many kinds of analog computer shared two crucial features. Firstly, as with the differential analyzer each quantity used in the computation was represented by a different part of the machine, and the relationships between these components were proportional (i.e. analogous) to those between the things being computed. Second, variations were continuous. In practice there were limits to precision. An operator might not trace a curve perfectly, for example. But in theory any variation, however slight, in the input should lead to a corresponding variation in the output.

As Kline showed, while the need to distinguish between these two fundamentally different approaches to computing was widely accepted during the mid-1940s the specific pairing of analog vs. digital was only one of many used to accomplish this – even among scientists connected to the NRDC. One pairing was between computers that measured and those that counted. Digital systems were sometimes called pulse or impulse computers, because many of them encoded numbers as electrical pulses. Others,

[6] Ibid., p. 454.

drawing on mathematical categories, described them as *continuous-variable* (or simply *continuous*) and *discrete-variable* (or simply *discrete*) machines. Stibitz himself used these alternative forms when giving a lecture at as part of the University of Pennsylvania's 1946 summer school for people interested in building electronic computers.[7]

By the end of the 1940s, however, the language of digital vs. analog language was generally accepted by those discussing automatic computers. Consistent use of "digital" by John von Neumann in his 1945 *First Draft of a Report on the* EDVAC, the first description of the architecture of modern computers, must have helped.[8] The concept of digitality was also applied, retroactively, to older computing devices. A 1949 article in *Scientific American* on "Mathematical Machines" surveyed the latest digital computers like ENIAC and IBM's SSEC, but went much further back in history. "The first artificial digital computing device," claimed science writer Harry M. Davis, "was the abacus, a manually operated mechanical memory of great antiquity." IBM punched cards, mechanical adding machines, teletypes, tape-controlled relay computers, and Charles Babbage's unfinished difference engine were also invoked as examples of digital technology. [9] While the presence of teletypes on the list suggests that Davis was already inching towards a concept of digitality that included encodings of text as well as numbers, the other examples were all literally digital in the sense that they encoded and manipulated numerical digits.

Davis understood that these numbers could be represented in many different media, some easily readable by humans (indeed, joined to the human body) and others invisible to our unaided senses. He explained "The Digital Idea" as follows:

> The digital computer is distinguished by the fact that it does not measure: it counts. It never responds to a greater or lesser degree; at every stage of its action, it is an 'all or nothing' device operating with discrete signals that either exist or do not exist. The simplest digital computer is the human hand, from which, of course, we have our decimal system. Corresponding to such primitive indicators of a numerical unit as a finger, a pebble, or a stylus scratch, the new automatic computers represent digits by such methods as: A round hole in a strip of tape. A square hole in a piece of cardboard. A current in an electromagnet. An armature attached to the magnet. A closed pair of electrical contacts. A pulse of current in an electrical transmission line. An electronic tube in which current is permitted to flow from filament to plate. A magnetized area on a steel or alloyed wire. A magnetized area on a coated tape. A darkened area on a strip of photographic film. A charged area on the face of a cathode-ray tube. A moving ripple in a tank of mercury.

[7] George Stibitz, "Introduction to the Course on Electronic Digital Computers", in *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers*, ed. Martin Campbell-Kelly and Michael R Williams (Cambridge, MA: MIT Press, 1985):3-16. As Ron Kline has observed, the word "digital" occurs only in the title of the lecture, but not in its actual text. Kline, "Inventing an Analog Past and a Digital Future". Given that the lecture was titled after the course as a whole, to serve as an introduction, it seems likely that it reflected the preferred terminology of organizers of the course (primarily Carl C. Chambers of the Moore School) rather than of Stibitz himself who was a last-minute substitute for the speaker originally scheduled to give the lecture.

[8] John von Neumann, "First Draft of a Report on the EDVAC," *IEEE Annals of the History of Computing* 15, no. 4 (October 1993):27-75.

[9] Harry M Davis, "Mathematical Machines," *Scientific American* 180, no. 4 (April 1949):28-39.

Although digital and binary are today often conflated, Davis was well aware of that decimal is no less digital than binary. Both are number systems that use digits, and both can be encoded in many different media, including digital electronics. Witness his advocacy for the abacus as the original digital computer, and his extensive comparison of the use of decimal, binary coded decimal, and pure decimal number systems for electronic computers.

Digitality as a Reading Practice

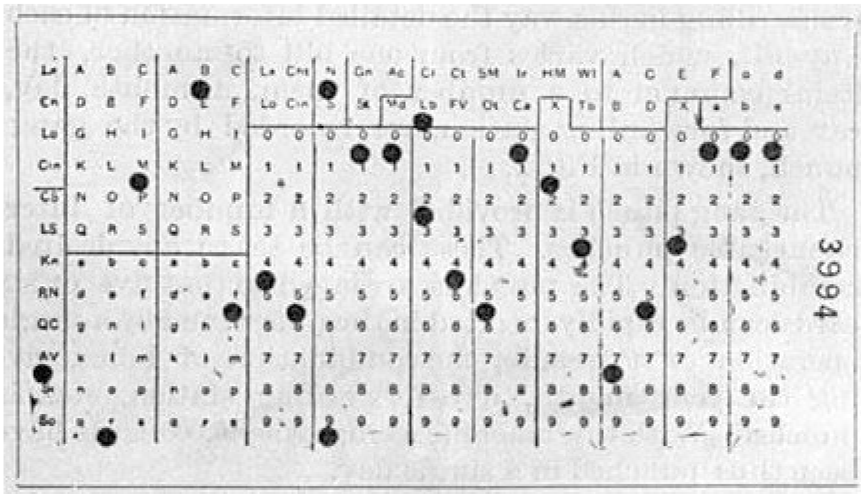
In the beginning, then, what made digital computers digital was their representation of quantities as digits and their manipulation of these digits by mechanizing the ordinary processes of arithmetic. They did their mathematics in the same ways learned by school children. Within each digital computer were mechanisms to encode digits. We term this sense of digital *numerical digitality* in the sense of numerical mathematics, which relies on the manipulation of digits to provide approximate solutions to equations.

Matter itself is neither digital nor analog. What is digital or analog is not an object itself, but the way in which an object is read. Digitality is active: the practice of examining a part, usually a very small part, of the world and classifying it as falling into one of a finite number of valid states. Digitality is enacted by reading practices. As we shall see in the next chapter, not all of the processes now viewed as digital involve actual digits. But the process of digital reading takes place literally if we attempt to read a telephone number written on a piece of paper, or peer myopically at a credit card trying to type the number it contains into a web browser. These number are inarguably and literally digital: strings of digits. Most of the numbers we deal with are written using Arabic numerals, which means that they are written out using the digits 0 to 9.

These are the digits that gave rise to the broader category of digitality. Reading them is made easier because there are only ten possible values for each digit and the symbols were chosen to be easily distinguished from each other. They can be misread – for example a badly formed 9 might be mistaken for a 0. But we cannot change their value by making them bigger or smaller as we might do in an analog system of representation. Neither can we represent a number part way between 1 and 2 by writing down a symbol that looks a bit like a 1 and a bit like a 2. If presented with a squiggle that doesn't clearly map to a valid representation of any of the ten digits we would either guess which it was meant to represent based on context or reject it as unreadable. These characteristics underly the discreteness of digital representations: each digit is constrained to one of ten possible values with no valid intermediate states.

Machines read digitally with sensor mechanism that controls part of the action of the machine. On this level there is no distinction between reading programs and data. That is true whether the mechanism in question directs a loom, increments an accumulator, or transmits an encoding of the information just read, thus transcribing it from one digital format to another. Some part of the machine must change from one state to another according to the value being read. That part might be a circuit that fills with current if a hole is punched in a certain position on a card, a hammer that strikes a string in a player piano when a hole is sensed on a roll of paper, or a sensor that changes its resistance in response to the momentary light fluctuations on a fiber optic cable.

Here is an example of a digital representation intended to be readable by both humans and machines. Punched cards holding numbers were introduced for the 1890 census. The original cards had 45 columns and twelve rows. The card as a whole could be read as containing a 45-digit decimal number, though in practice cards usually encoded several distinct data fields of a few digits each. Space on the card could be partitioned to code different data fields. Within each field, only one hole was punched – akin to a person representing a digit by folding one of ten digits of their hands. Tabulating machines were configured accordingly, to total the values stored in specific fields from cards that met certain criteria. IBM machines produced from 1928 onwards standardized on a larger, 80 column card.



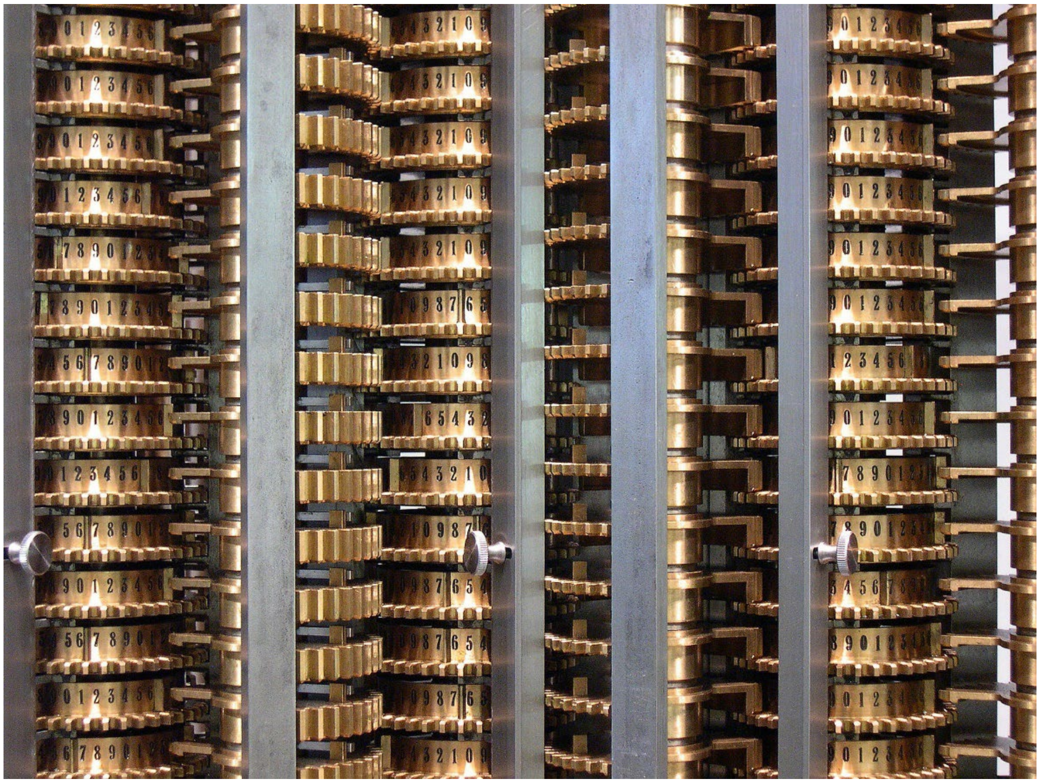
An example punched card in the early 24 column format, taken from an 1895 issue of the Railway Gazette. Most of the fields represent two and three digit decimal numbers, in a format that could be tallied automatically by tabulating machines. The non-numeric fields were used to sort and filter the cards. Printed labels on the card aided human legibility. [10]

Numbers on punched cards could be read by humans and by machines, though with different practices. Humans used complicated neural mechanisms to interpret light reflected from the cards. Tabulating machines probed the card with electrical connectors, using the values encoded in particular columns to sort cards into one pile or another or to increment counters.

Although Harry Davis insisted that digital reading involve signals with just two states, *existing* and *not existing,* this is not always the case. Many digital systems, for example, distinguish between ten different states representing the ten decimal digits. Sometimes, as with the punched cards (or with counting on one's fingers) ten different values of a decimal digit are represented with ten different object, which is which has one two states, such as punched or not punched. In other cases, there may be one object with ten valid shapes or positions – as with digits written on a piece of paper.

Mechanical adding machines and calculators all had to use some mechanism to represent digits. Most did it with cog wheels of one kind or another, rotating through ten different positions. When a wheel advanced from 9 back to 0 it would push the wheel next to it to advance by one position, performing a carry to the next digit place. Rather than being an "all or nothing" signal, the wheel had ten stable positions.

[10] (https://en.wikipedia.org/wiki/Punched_card#/media/File:Hollerith_punched_card.jpg)



A detail from the mechanical difference engine constructed by the London Science Museum according to the design of Charles Babbage. The position of each wheel encoded a single decimal digit; each column encoded a full number. A full rotation of a wheel caused the wheel above it to advance by one place, carrying 1 to the next digit as it reset to zero. Linkages from between wheels allowed the machine to add together the contents of adjacent columns. Humans read the numbers by looking at the markings on the wheels. The leftmost column was connected to a printing mechanism, able to read and transcribe its value once the computation was complete. [11]

Analog to Digital Conversion

Digits have such a good fit with processes of tallying that the difference between analog and digital was sometimes expressed as the difference between measuring and counting.[12] If we are attempting to count the number of times the word "digital" appears in this text, or the number of marbles in a jar, the result will be a whole number (technically, a positive integer) which can be expressed in digital form with no loss of precision. In mathematical terms, the thing being counted is itself discrete. The digital representation can capture the quantity perfectly.

Sometimes we must assign digits to approximately represent the value of something continuous. Imagine we are using a ruler to measure the length of an object, or a traditional thermometer to measure a temperature. The thermometer itself is analog: as its temperature rises and falls the fluid within expands and contracts proportionally. To read a thermometer we turn that continuous variation

---

[11] https://en.wikipedia.org/wiki/Difference_engine#/media/File:LondonScienceMuseumsReplicaDifferenceEngine.jpg

[12] In the mid-1940s Norbert Wiener, the founder of cybernetics, preferred the terminology of *measurement device*/*counting device* to *analog*/*digital*.

into a number. In both cases we visually compare the length of something continuous to a measuring scale marked out with gradations. We pick the closest marking and record a length as 87mm, an angle as 27 degrees, or a temperature as 39.5 degrees. In doing this we map the analog reality of continuous variance onto whichever number seemed closest. If we have access to a better instrument, or a magnifying glass, we might be able to specify the result to a higher degree of precision, adding digits after the decimal point.

The processes described above are known as analog to digital conversions. Early on the distinction between analog and digital was often made in terms of measuring versus counting. Analog to digital conversion is the process of turning a measurement into a number.

Digital systems approximated the continuous variability of the natural world by encoding a finite sequence of digits, each of which was restricted to a predetermined set of possible values (0-9 for decimal, 1 and 0 for binary, and so on). It might seem odd to focus here on the representation of numbers using a finite set of encoded symbols as the original hallmark of digitality. We should distinguish here between numbers and digits. As children learn in school the set of integers is infinite because any number, however large, can be incremented. Each digit has only ten possible values. But two decimal digits together have one hundred possible values, three have a thousand, and so on to infinity. We can always add more digits to the sequence. By introducing a decimal point, sequences of digits can be made to approximate fractions.

Reading vs. Writing

Why do we call digitality a way of reading, rather than way of writing? Surely the digits extracted from a mechanism, or read from a scrap of paper, had to be written before they were read. Thus, you might suggest, it is the act of writing a message encoded in a finite set of possible symbols, or perhaps the conjunction of writing and reading, that define digitality.

Yet the digits produced by the process of digital reading were not always encoded by a sender. In fact, many digital reading practices capture information from nature. Consider, for example, a digital thermometer –a widely used modern device that is literally digital in the sense proposed by Stibitz back in 1943. It automates the measuring process required to use a conventional thermometer. The thermometer measures the ambient temperature, i.e. the thermal energy of molecules in the environment, and outputs a set of digits. This is a form of digital reading. The digital encoding used is determined by the machinery, but the content of message comes from nature.

This digital thermometer automates the process of digital reading traditionally carried out by a human peering at the gradations marked along the side of a tube containing mercury or alcohol.[13]

The same is true, on a vastly greater scale, of images produced by digital cameras. Each of the many millions of pixels in the sensor array is measuring the intensity and color of the light falling on it and converting this to a numerical value.

One might attempt to distinguish between digital sensors of this kind, each measuring a single value, and the act of reading which involves looking at a sequence of coded symbols. But sampling values from a sensor at regular intervals, as the analog to digital converters used in digital audio recorders do, will produce a time sequence of values.

Nature includes at least one example of a more complex digital code with no human author. Historians of science have written about the use of information theory by researchers investigating DNA in the 1950s. The very phrase "genetic code" makes assumptions tied to information theory and digital communication. Attempts were made, without much success, to use analysis of this kind to make predictions about how genetic information was stored and, once the role of DNA was clear, how base sequences coded for particular amino acids. Suddenly chemical sequences without a human author were being treated as a medium, holding a digital message. The title of Lilly Kay's book *Who Wrote the Book of Life* captures her objection to this: researchers viewed themselves as reading a text but were in fact constructing one, bring ideas from information theory that hindered more than they helped.[14] Her point is an interesting one, but subsequent developments in gene sequencing and manipulation suggest that the digital information perspective on the genome eventually became a source of leverage. The six billion nucleotides contained in a genome can be read and transcribed into a data file that fits comfortably inside a modern smartphone. While the connection between that data and human life is

---

[13] https://en.wikipedia.org/wiki/Thermometer#/media/File:1024_Pyrometer-8445.jpg

[14] Lily E Kay, *Who Wrote the Book of Life: A History of the Genetic Code* (Stanford: Stanford University Press, 2000).

not fully understood, it can nevertheless be searched for informational markers signaling traits and disease tendencies.

Thus digitality always involves a practice of reading that maps a continuous range of possible states in the physical world, such as the almost infinite range of actual temperatures, onto one of a finite number of possible states. In some cases, such as reading numbers from a punched card, the effect of this process is intended to be the recovery of information deliberately written to the medium. But in other cases, such as a digital thermometer or digital audio recording, the information captured by the digital reading practice was not deliberately encoded by an author.

Representing Numbers With Switches

As Harry Davis recognized in his 1949 article popularizing the concept of digitality, the new idea described many earlier technologies but had been introduced to held categorize a proliferation of new ways of encoding numbers using electronic and electromechanical methods. The engineering techniques used to build electronic digital computers have several historical origin points. One is in electronic circuits used to tally, a technique pioneered in the 1920s and 1930s by physicist Charles E. Wynn-Williams for use in nuclear physics instrumentation.

Another, and the one we shall focus on here, is in switching. Automatic telephone exchanges, introduced for local calls in the early twentieth century, received decimal digits as sequences of pulses generated as telephone dials rotated themselves back to their resting positions. The exchange equipment read these pulses digitally, tallying them by advancing its switching equipment to its next position each time a pulse was received. The next digit dialed on the handset, represented as another sequence of pulses, controlled the next switch.

US telephone numbers used three digits to code which exchange within a city the call should be directed, and thus told the local exchange of the caller which cable to switch the connection onto. Once this connection was made, the last four digits set the switches in the destination exchange to complete the electric connection from the caller’s telephone line to the telephone line whose number had been dialed.[15] Automatic dialing of calls between cities, which added an additional three optional digits for long distance connections, automatically took a few decades more to become widely established because of the complexity of the task. Switching equipment was bulky. AT&T spread local exchanges throughout the neighborhoods served, and built central exchanges for major cities in large, windowless buildings.

The relay, a switch that turned on and off under electrical control, was invented for telegraphy. Hence the name: relays were first used to boost and repeat signals on long distance lines. But they could also be used to switch telephone calls. In 1937, Claude Shannon was part way through a master’s degree in engineering at MIT when he was hired for a summer internship by Bell Labs. His exposure to its network of switching circuits, the most complex in the world, provided him with the subject for his thesis. Shannon had already experienced analog computing, as an operator of Bush’s differential analyzer, but he conceptualized the switching circuits he encountered at Bell Labs in terms of logic rather than

[15] The same system had been used with human operators, with the destination exchange specified by name and only the last four digits given numerically. To help in switching between the two methods, which coexisted for decades, letters were printed on the dial and exchange numbers were chosen to correspond with the names of the exchanges to make them easier to remember.

numbers. In switching circuits, wires either carried electrical pulses or they didn't. Relays opened or closed. It would be five years until Stibitz, also of Bell Labs, would introduce the terminology of digital and analog. Shannon drew not on numerical mathematics but on mathematical logic, specifically Boolean algebra. He equated switched that were turned on with logical statements that were true, and switches that were turned off with logical statements that were false. The circuits used to interconnect those switches corresponded to the basic logical operators: AND, NOT, and OR. Shannon argued that switching circuits could be converted into logical expressions. Once expressed algebraically the circuits could be manipulated to transform them into the simplest possible representations, which could in turn be mapped back onto circuit diagrams, ensuring that the simplest and most efficient designs would be used. The vocabulary later used to talk about digital electronics: digital logic, logic gates, truth tables, and so on is rooted in this equivalence of digital circuits and logical propositions. Shannon also equated true with 1 and zero with false, providing numerical interpretations of the switches which he showed, in one of his examples, could be used to create a binary adder. [16]

Shannon's thesis has been called the most consequential master's degree thesis in history, though historians have argued against the assumption that this one document can explain a revolution in engineering practice. For one thing, Shannon was not the first or only person attempting to combine logic and circuit design. For another, his method took considerable refinement over many years before it was used for practical purposes by ordinary engineers.[17]

Relay switches of the kind used in some 1930s telephone exchanges and many early digital computers rely on a metal strip to move physically from one position to another, and thus could switch at most a few hundred times a second. That was more than enough to keep up with the speed of a telephone dial, but it put a severe cap on the maximum speed of a digital computer. The Harvard Mark 1 computer, built by IBM and installed in 1944, took three seconds to carry out a multiplication.

Electronic circuits could switch much faster than relays. One of the crucial building blocks of digital electronics is the flip-flop circuit, also known as the latch. This is the electronic equivalent to a relay switch. The circuit has two stable states, meaning that it stores a single bit of information. Its output line carries either a high or low voltage, to allow other circuits to read its content. The information stored in it will persist until a pulse is received on its reset line, which primes it to store the value provided at that instant on its input line. Early digital electronics used two vacuum tubes to produce a flip-flop; later systems used two transistors. Each flip-flop was the equivalent of a single relay switch.

In a sense, analog to digital conversion occurs all the time inside digital computers. Within computers and other digital electronic devices most digital reading map objects onto a set of just two valid states, typically corresponding to the binary digits 1 and 0 or to true and false. Consider, for example, computer electronics. When data is being moved around insider a computer, voltage levels on a given data or address line rise and fall millions of times every second. We talk of computers being stuffed with 1s and 0s, but those states are actually represented by high and low voltages. Traditionally a 5 volt power supply is used. Ideally the power supply would give a constant output of exactly 5 volts, and logic gates

[16] Jimmy Soni and Rob Goodman, *A Mind at Play: How Claude Shannon Invented the Information Age* (New York, NY: Simon & Schuster, 2017)@ch. 4.
[17] Maarten Bullynck, "Switching the Engineer's Mindset to Boolean: Applying Shannon's Algebra to Control Circuits and Digital Computing (1938-1958)", in *Exploring the Early Digital*, ed. Thomas Haigh (Cham, Switzerland: Springer, 2019):87-99.

would switch instantly from 5 volts to 0 volts. In practice though, power supplies fluctuate and give only approximate voltages and components do not switch instantly or conduct perfectly. So the manufacturer of a chip might guarantee that it will treat inputs between 5 volts and 2 volts as high, and all inputs of between 0.8 volts and 0 volts. This is called thresholding. The continuous variation of the actual voltage compressed into just two valid states.

Because electronic systems so often rely on reading methods with only two valid values it is common to conflate digital and binary. This is not true, even for electronics. One could, for example, use voltages from 0V to 9V to encode the digits 0 to 9, rounding off to the nearest volt. A value of 2.2V would be rounded to 2, of 4.9V to 5, and so on. But the circuitry required to do this would be far more complex, and far more likely to be read incorrectly. In practice, digital electronic computers have relied almost entirely on two-value encodings, whether or not they use binary arithmetic. Even computers built using tenary (base 3) rather than binary logic and arithmetic still relied on two-value hardware in their memory units and logic circuits. This meant that each trit (tenary digit) was encoded inefficiently as two bits.[18]

Each flip-flop stored a single bit, but the circuits were joined together to store larger numbers. For example, eight flip flops could store an 8-bit binary number, which since the 1960s has been known as a byte. This simplifies the design of computer logic – binary and multiplying circuits are trivial in comparison to their decimal equivalents, though using binary does create extra work to convert output into decimal form for the benefit of humans. But the same circuits could also be used to represent decimal numbers. ENIAC, the first programmable electronic computer, was entirely decimal.[19] It grouped together ten flip-flops to represent a single decimal digit, in an assembly known as a "ring counter." Only one of the ten flip-flops was active at a time. Each input pulse to the counter advanced its position by one, for example from 3 to 4. This design was conceptually straight forward – the electronic equivalent of a cog with ten possible positions or a card punched in one of ten holes. But using hardware capable of storing ten bits to store just one decimal digit was inefficient. Other early computers that used decimal, rather than binary, arithmetic packed their digits more effectively, storing each decimal digit in just four bits by coding digits with combinations of active flip-flops. IBM continued to use decimal number representations in its computers intended for business use well into the 1960s, and its competitors Univac and Burroughs also released decimal machines. As Davis noted in his 1949 article, this method was far more efficient, allowing IBM's SSEC to represent each decimal number using less than half the number of tubes requirement by ENIAC.

---

[18] Francis Hunger, *SETUN: An Inquiry into the Soviet Tenary Computer* (Leipzig, Germany: Institut für Buchkunst Leipzig).

[19] Or at least ENIAC used only the decimal number system and made no use of the binary number system. One can distinguish here between two senses of the word binary. The most general is to describe a choice with only two valid values. For example, the traditional but now disparaged idea of gender. The most common is to describe the base 2 numbering system. Almost all digital electronic logic is binary in the former sense, because it is based around components that signal to each other using two valid states. Those signals may or may not represent numbers coded in binary. In talking about digital computers, however, the conventional way of classifying them is according to the numbers coded by these pulses. Some computers performed their arithmetic on decimal numbers, some on octal numbers, some on binary numbers, and some on hexadecimal numbers.

Conclusion

The modern discourse of digitality has departed quite dramatically from a direct connection with the literal representation of digits. Some so-called *digital formats*, such as those for audio and video do involve the conversion of analog inputs to encoded numbers but this is rarely what people have in mind when they talk about *the digital* or about *digital cultures*.

In fact, the concept of digitization, while literally extremely appropriate, has rarely been invoked by people discussing processes of quantification as used, for example, by governments to describe their populations. Neither would a *digital historian* be liable to risk confusion with a *quantitative historian* (particularly as the latter are virtually extinct, while the former have recently proliferated).

Yet it is, we feel, important to emphasize the early and enduring connection of digitality with digits. Digits are digital, whether counted on figures, written on paper, encoded on a punch card or represented by minute electrical fluctuations. By the 1950s, however, the concept of digitality was broadening to include systems of representation based on sequences of symbols of any kind, not just on encoded digits. As we shall see in the next chapter this reflected both the evolution of computer technology toward non-numerical applications and the conceptual influence of Claude Shannon's mathematical treatment of communication.

Bullynck, Maarten. "Switching the Engineer's Mindset to Boolean: Applying Shannon's Algebra to Control Circuits and Digital Computing (1938-1958)." In *Exploring the Early Digital*, edited by Thomas Haigh, 87-99. Cham, Switzerland: Springer, 2019.

Bush, Vannevar. "The Differential Analyzer. A New Machine for Solving Differential Equations." *Journal of the Franklin Institute* 212, no. 4 (October 1931): 447-488.

Davis, Harry M. "Mathematical Machines." *Scientific American* 180, no. 4 (April 1949): 28-39.

Hunger, Francis. *SETUN: An Inquiry into the Soviet Tenary Computer*. Leipzig, Germany: Institut für Buchkunst Leipzig.

Kay, Lily E. *Who Wrote the Book of Life: A History of the Genetic Code*. Stanford: Stanford University Press, 2000.

Kline, Ronald R. "Inventing an Analog Past and a Digital Future." In *Exploring the Early Digital*, edited by Thomas Haigh, 19-39. Cham, Switzerland: Springer, 2019.

Mindell, David A. *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics*. Baltimore: Johns Hopkins University Press, 2002.

Owens, Larry. "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer." *Technology and Culture* 27, no. 1 (January 1986): 63-95.

Peters, Benjamin. "Digital." In *Digital Keywords: A Vocabulary of Information Society & Culture*, edited by Benjamin Peters, 93-108. Princeton, NJ: Princeton University Press, 2016.

Soni, Jimmy, and Rob Goodman. *A Mind at Play: How Claude Shannon Invented the Information Age*. New York, NY: Simon & Schuster, 2017.

Stibitz, George. "Introduction to the Course on Electronic Digital Computers." In *The Moore School Lectures: Theory and Techniques for Design of Electronic Digital Computers*, edited by Martin Campbell-Kelly and Michael R Williams, 3-16. Cambridge, MA: MIT Press, 1985.

von Neumann, John. "First Draft of a Report on the EDVAC." *IEEE Annals of the History of Computing* 15, no. 4 (October 1993): 27-75.

1.2: What's Digital About Digital Communication?

Thomas Haigh & Sebastian Giessmann

In the first chapter we explored the origins of the digital/analog divide in the discourse around early automatic computers in the 1940s. Yet once the categories of digital and analog were invented, contemporaries immediately used them to categorize earlier technologies for the representation of numbers and quantities such as slide rules and adding machines.

Digital computers were digital in a direct, non-metaphorical sense: they mechanically or electronically encoded the values of digits and manipulated these encodings to perform calculations. Building on this history, we argued for an analytical conception of digitality centered on processes of reading, by which the continuous variation of the natural world is mapped onto one of a finite, and usually small, set of valid states.

This chapter continues work on both fronts by looking at the historical broadening of the concept of digitality to include non-numerical systems of representation such as those used to encode text and pictures. This conception underlies the ability of computers to deal with things other than numbers, but it has its roots in communications theory, most famously in the work of Claude Shannon. In parallel with our historical description of the emergence of non-numerical conceptions of digitality we broaden our analytical treatment of digitality to encompass more historical technologies and reading practices: not only adding machines and punched cards, but also musical boxes, weaving systems, movable type, and even alphabets and hand gestures.

The affordances of text, of punched cards, and of paper tape are not identical but they all encode sequences of symbols. This perspective demystifies the arrival, in the mid-1940s, of programmable computers. They embodied practices of digital reading comparable to those carried out by earlier machines and by humans. The addition of branching and looping capabilities, while highly consequential, was a refinement of digital control.

Digital Information Theory

In many digital systems the signals do not represent numbers at all. That marks a conceptual shift from the origins of the digital/analog divide in discussion of computers, since these machines were called digital precisely because they represented numbers as digits.

Over time, however, the association of digitality with digits has weakened in favor of another sense of digitality: the engineering sense of digitality as defined by the study and engineering of digital signals that carry encoded information. This owes much to the other contribution of Claude Shannon: his mathematical theory of communication, or as others termed it, information theory. [1] Shannon's work on the topic was initially published in his classic 1948 paper, "A Mathematical Theory of Communication."[2] In the decade since the completion of his master's thesis Shannon had earned a Ph.D. in mathematics, spent a year as a visiting fellow of the Institute for Advanced Studies in Princeton, and then returned to

[1] Ronald Kline, "Cybernetics, Management Science, and Technology Policy: The Emergence of 'Information Technology' as a Keyword," *Technology and Culture* 47, no. 3 (July 2006):513-535.
[2] Claude E Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal* 27 (July & October 1948):379-423, 623-656.

Bell Labs full time to work during the war with Stibitz and Bell Labs on the NRDC’s gun direction contract and on cryptography. His performance quickly earned him a permanent job in its mathematics research group.[3]

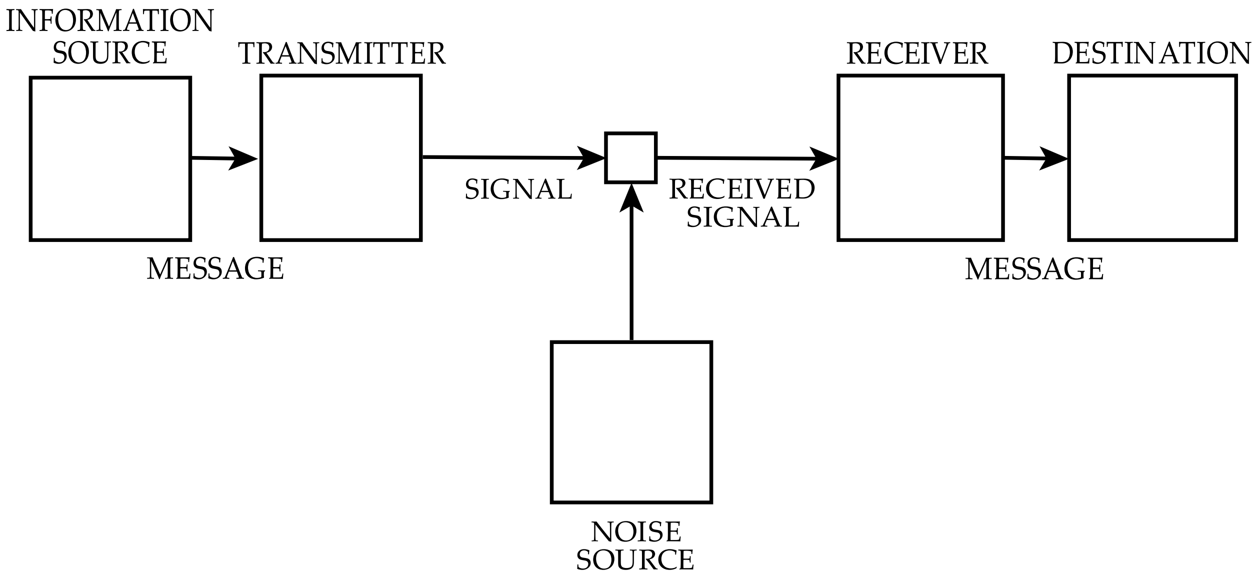
As with Shannon’s earlier work on switching circuits, his theory of information was not the transformative work of a lone genius. Historians stress the extent to which his work drew on both his collaborative wartime experience and earlier efforts to describe information transmission mathematically undertaken by his Bell Labs colleagues such as Rupert Hartley and Harry Nyquist from the 1920s onward.[4] For our purposes we need not disentangle the personal contributions of Shannon to his new synthesis, merely assert that his work was the path by which the new ideas made their way into the broader world.

Our claim that Shannon’s landmark paper played an important role in defining a new, and much broader, sense of *non-numerical digitality* may seem startling because it does not contain the words *digital* or *analog*. Instead Shannon preferred to talk about *discrete* versus *continuous* functions – an echo of the terminology used by Stibitz two years earlier in his Moore School lecture. We believe that the choice reflects Shannon’s knowledge that the process he described did not necessarily involve converting the information being communicated into digits, making *symbol* a more natural choice than *digit* and *discrete* more meaningful than *digital*.

In modern terms, or even according to definitions that would be accepted just a few years later, Shannon’s paper is unmistakably a treatment of digital communications and digitization. Shannon acknowledges in its first sentence that interest in a “general theory of communication” had been motivated by the development of pulse code modulation, the basic technique for the digitization of audio. This technique uses high speed sampling to turn an audio stream into a sequence of numbers. Shannon’s self-proclaimed general theory of communication is often depicted as a model that encompasses techniques such as voice communication over analog telephone lines. But the paper is unambiguously a mathematical theory of *digital* communication. Shannon begins by proposing the bit, a termed coined for the occasion by John Tukey, a Princeton mathematician working at Bell, as the basic unit of information. On the second page Shannon defines the thing being transmitted as a message consisting either of a sequence of letters or, essentially, as one or more functions giving numbers that change over time (in one dimension for audio, in multiple dimensions of time and space for video). After that nod to the possibility of non-textual encoding the rest of the paper focuses squarely on text.

[3] Shannon’s career is described in Jimmy Soni and Rob Goodman, *A Mind at Play: How Claude Shannon Invented the Information Age* (New York, NY: Simon & Schuster, 2017).

[4] Statisticians also began to conceptualize information as something quantifiable during the same period. Ronald Kline, *The Cybernetics Moment, Or Why We Call Our Age the Information Age* (Johns Hopkins University Press, 2015), 22.

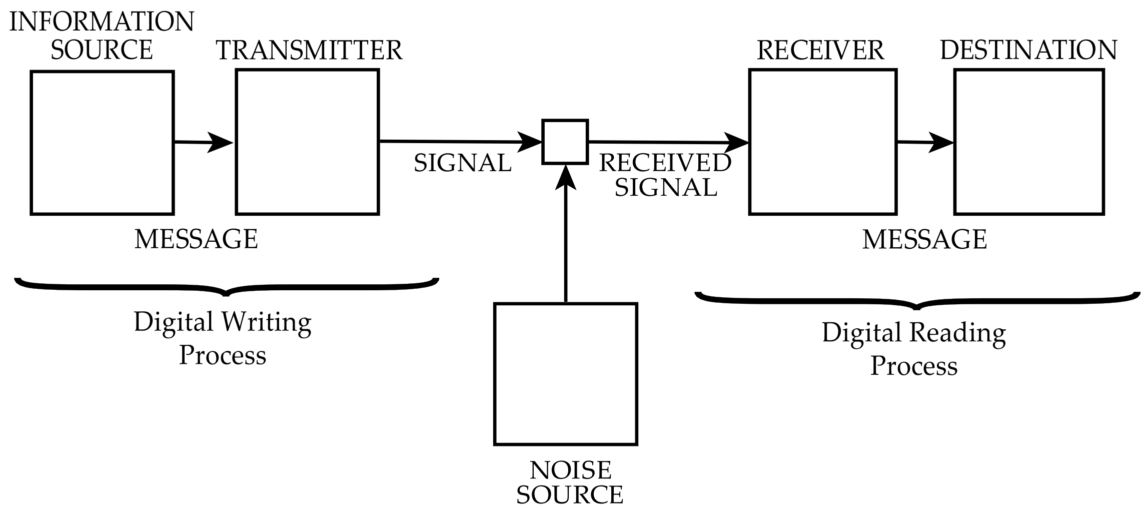


Shannon's schematic representation of a "general communication system" distinguished between the message itself and the signal transmitted after the message had been encoded. Shannon conceptualized the message as a sequence of symbols. The task of the receiver was to interpret the received signal to identify each coded symbol transmitted, thus reconstructing the original message.

Shannon called the bit rate available on a given communication channel its "bandwidth." He used the word *digit* thirty times in the paper when discussing methods to quantify the information content of these messages. The bit, which is after all a contraction of "binary digit" is a fundamentally digital concept. As Shannon pointed out, to transmit a "continuous" (analog) signal exactly would require infinite bandwidth. Thus the information content of an analog signal can be measured only by digitizing it, or as Shannon put it, by defining the required "fidelity of recovery" and using this to define "a rate, having the property that is it possible, by properly encoding the information, to transmit it over a channel whose capacity is equal to the rate in question, and satisfy the fidelity requirements."[5]

In our conception, which we believe aligns with historical usage, digitality describes a class of reading practices. From this viewpoint the act of digital reading, i.e. sensing something in the world and mapping it to one of a finite number of valid states, is equivalent to the right hand side of Shannon's widely reproduced diagram.

[5] Claude E Shannon, "A Mathematical Theory of Communication," 47.



We conceptualize the processes on the left side of Shannon’s diagram as the act of writing digitally into a communication channel; we conceptualize the processes on the right side as reading digitally from the same channel.

The system described by Shannon, in which the signals read digitally by the receiver were deliberately encoded and placed into a channel with the intention that they be received and recoded, describes the combination of digital reading with digital writing. As we mentioned earlier, some digital reading practices, such as the action of a digital thermometer or a digital audio recorder, apply digital reading to inputs that were not deliberately encoded by an identifiable sender.

Symbols Versus Numbers

Shannon conceptualized the message being transmitted as a sequence of symbols, chosen from a finite set. While he measured the information content of this sequence in bits, he did not require the symbols themselves to be numbers. This may be why Shannon, and even his Bell Labs colleague Stibitz who had introduced the digital/analog distinction in the first place, had come to prefer continuous/discrete to analog/digital as a description for the two approaches. *Digital* made sense as a description for a computer project because the symbols being manipulated by the computers of the period were digits. The computers were fed input digits, carried out mathematical operations on them, and output digits. ENIAC’s card punch interface, for example, was physically incapable of punching more than one hole in each column of the card and so could not output anything other than a single decimal digit in each column. As a general term for communication, in contrast *digital* left a lot to be desired because most messages did not consist entirely of digits.

The ideas in Shannon’s paper were shaped by his wartime experience in encrypted communication projects. These wartime projects were important for the emergence of what would soon be called cybernetic thinking and for the concept of *communication* as an area of study. Peter Galison famously located the origins of Nobert Wiener’s “cybernetic vision” in his experiences working alongside Shannon on the gun director project.[6] Indeed, Wiener’s famous book *Cybernetics* carried the alternate title

[6] Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21, no. 1 (Autumn 1994):228-266.

“Control and Communication in the Animal and the Machine.”[7] In cybernetics, “communication” turned into an operative concept that combined communication and programmed control in circular feedback loops

According to Erhard Schüttpelz the notion of *communication* “became visible in the change from the theory and practice of secret communication, from the command basis of military communication to the common user basis of mass communication—between the manipulation of mass communication and its civil population, and old and new promises of autonomy and democracy.” More specifically, asserted Schüttpelz, “Shannon’s famous communication diagram is both a telegraphic and a one-way model—a telegram.”[8]

Indeed, the first example Shannon presented to introduce his concepts was one of encoding the 32 symbols used in the standard teletype alphabet. His next example involved an alphabet containing only the letters A, B, C, D and E. From this viewpoint, the challenges involved in transmitting a sequence of numbers or a sequence of letters are identical. Letters are not digits, even if they the two can be interchanged with a trivial effort, but both are symbols drawn from a finite set. The process of measuring the information content of a message, by converting from the appropriate base for the number of symbols to base 2 (binary), hinged on the equivalence of symbols and digits. To Shannon the interchangeability of digits and numbers was already too obvious to explain or justify. Ciphers involving the conversion of letters to numbers had been around for centuries, and the bit patterns punched in paper tape for teletype transmission could be read just as easily as representing the numbers 0-31 or the teletype alphabet.

Hence *symbol* and *message* were better terms to describe the information being transmitted than *digit* and *number*. It followed that *discrete* was a better word than *digital* to describe the encoding used to transmit the message. Likewise, *analog* made sense for computers in which specific components played roles analogous to quantities in the system being modelled but made less sense for describing the transmission of a regular telephone call. Continuous, on the other hand, is a precise description of variance in the current transmitted down the wire. Shannon’s paper was hugely influential, but he did not get his way with respect to vocabulary. Communications engineers finished up adopting the terminology of analog versus digital that had been introduced to distinguish between kinds of computers, while Shannon became famous as the creator of *information theory* despite publishing his paper as a mathematical description of *communication*. The result was a redefinition of all three terms:

---

[7] Norbert Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine* (Cambridge, MA: Technology Press, 1948).

[8] Erhard Schüttpelz, "'Get the message through’: From the Channel of Communication to the Message of the Medium, 1945–1960", in *Media, Culture, and Mediality: New Insights into the Current State of Research*, ed. Ludwig Jäger, Erika Linz, and Irmela Schneider (Bielefeld: transcript, 2010):109-138. We should, however, acknowledge that much work being done at Bell Labs during the same era focused on voice transmission including efforts that later proved foundational to audio compression and digital voice transmission. For this reason, Mara Mills has argued for the central place of telephony, rather than telegraphy, in new media history. Mara Mills, "Media and Prosthesis: The Vocoder, the Artificial Larynx, and the History of Signal Processing," *Qui Parle* 21, no. 1 (Fall/Winter 2012):107-149.

digital now applied to all symbols rather than just digits, *analog* to any system of continuous variation, and *information* to anything coded digitally.[9]

Shannon made two crucial points about the encoding of symbols. First, their appearance in messages is not random. In English, for example, certain letters are much more common than others. Beyond that, though, characters tend to cluster together in fixed patterns as words, and even words tend to follow each other in predictable patterns. (Such insights were vital to wartime codebreaking efforts, something nodded to by Shannon in a reference to "certain known results in cryptography"). In mathematical terms, the transitions from one symbol to the next are not random. Shannon claimed the redundancy of English text was about 50%, meaning that a message could usually be reconstructed accurately if fifty percent of its characters were deleted. This is the animating concept behind the classic game hangman and the long running TV gameshow *Wheel of Fortune* – contestants request the most common letters first and may attempt to guess a phrase when most of its letters remain obscured.

Because of this redundancy if English text was encoded using a simple method, with five bits per letter, the information content would be only about half that of an optimal coding mechanism. Efficiency could be improved by using shorter codes for the more common characters or character sequences, which Shannon termed compression of the message. A few years later an MIT student, David A. Huffman, came up with a method that he proved was optimum for coding messages where characters occur with different frequencies (assuming, unlike English, messages had no dependencies from one character to the next).[10]

The idea of encoding different symbols using codes of different lengths had a long heritage in communications. While teleprinter codes, Shannon's explicit example, used five bits for each character (something inherent to the five channel tapes used to hold messages) the Morse code used in conventional telegraphy and radio communication used shorter codes for more common symbols. It translated the message one character at a time into combinations of three symbols: dot, dash, and space (used only to mark the end of each character). The most common letter, E, was coded with a dot and a space. In contrast, Y, a less frequently used letter, was coded as dash, dot, dash, dash, space. The codes for digits all consisted for six symbols, again ending in a space. In a sense two translation processes took place each time a message was sent in Morse: first from English characters into dots, dashes, and spaces, and then from dots, dashes, and spaces into the on/off code sent by the operator using a spring-loaded Morse key. If we equate 1 with the depression of the key for a time interval and 0 with the key not being depressed, a dot was coded as 1000, a dash as 111000, and a space as 0000000. Time intervals were of course approximate, but the process of digital reading by the recipient listening to beeps on the other end of the wire could nevertheless be highly reliable because of the degree of redundancy. The gap between characters was more than twice as long as the gap between symbols and a dash was supposed to be three times as long as a dot. The need to ensure that the three symbols were reliably differentiated by human senders and receivers thus introduced a considerable amount of inefficiency into the transmission of Morse code.

---

[9] For a close examination of the Postwar development of cybernetics its relationship to the new sense of information see Kline, *The Cybernetics Moment, Or Why We Call Our Age the Information Age*.
[10] David Huffman, "A Method for the Construction of Minimum-Redundancy Codes," *Proceedings of the IRE* 40, no. 9 (1952):1098-1101.

Shannon's other crucial point was that no communication channel is entirely error free. A certain proportion of the symbols dispatched will be garbled in transit, represented in Shannon's diagram by the box injecting noise into the channel.[11] Shannon discussed ways to select coding schemes to minimize this. He drew on the work of Richard Hamming, one of his colleagues at Bell Labs, who had shown that by introducing redundancy into the coding of the message it was possible to detect these errors. Hamming subsequently developed a comprehensive treatment of error correction and detection.[12] Messages are split into blocks, packed with redundant information in the form of "parity bits." Adding more information allows for the detection of more errors, but at the price of a longer sequence to be transmitted and hence a lower effective bandwidth. By making the signal sequence even longer, enough redundancy can be included to allow the correction of errors as well as their detection. For example, one popular coding method, SECDED, allows correction of a single error in each block and detection of two errors. There is always a tradeoff in the choice of block size and the amount of redundancy: accuracy and reliability of transmission versus speed of transmission. The optimal choice on the expected rate of errors, the severity of allowing the occasional undetected error (far more serious in a code download than an audio stream, for example), and the importance of error correction (in many applications reliable detection of errors is enough, since the receiver can request retransmission).

Non-Numerical Digitality

Not all of the complex electronic machines of the 1940s dealt with encoded digits. Perhaps the most interesting example of a machine that is digital in terms of symbol processing but not in terms of processing numbers is the Colossus codebreaking machine (in fact a family of machines) employed at Bletchley Park during the Second World War. One of us has argued elsewhere that Colossus was not, despite frequent claims to the contrary, a computer and that it could not be programmed, though it could be extensively configured. [13] Instead, Colossus could perform logical comparisons between bits taken from ten bitstreams: five of them read from paper tape, and five generated by electronic circuits designed to mimic the encoding wheels of specialized Lorenz teleprinter encrypting attachments. The bits had no numerical significance: Colossus had no hardware capable of interpreting successive bits, or bits read simultaneously from multiple channels, as encoding a binary number. All it could do was to compare bits according to logical functions coded on switches and a plugboard and tally the number of times that the conditions in question were met during the reading of a tape (usually a tape holding an intercepted and encrypted message).

Colossus was not digital in the sense of a digital computer, because the bits did not represent numbers. But it was certainly digital in the broader, Shannanonesque sense of a machine that read information coded discretely as a sequence of symbols. Even this language of *bits* and *bitstreams* is problematic with respect to Colossus. The term "bit" had not yet been invented when Colossus was designed, so was not used at Bletchley Park. The staff at Bletchley Park talked not in terms of 1s and 0s, or even of true and false, but of a "teleprinter alphabet" containing just two characters: dot and cross. Can one responsibly

---

[11] The origin of the term *noise* in this context is explored in Mara Mills, "Deafening: Noise and the Engineering of Communication in the Telephone System," *Grey Room*, no. 43 (Spring 2011):118-143.

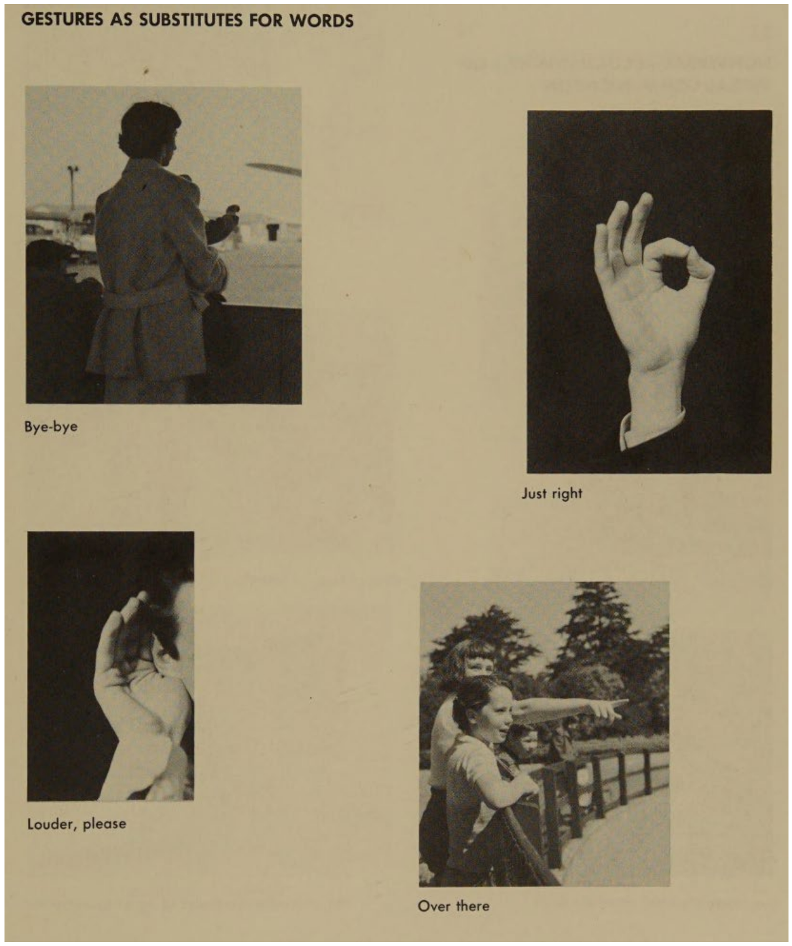
[12] Richard W Hamming, "Error Detecting and Error Correcting Codes," *Bell System Technical Journal* 29, no. 2:147-160.

[13] Thomas Haigh and Mark Priestley, "Colossus and Programmability," *IEEE Annals of the History of Computing* 40, no. 4 (Oct-Dec 2018):5-17.

speak of *bits* in this context given that the word is, as Shannon frequently reminds us, a contraction of binary digit? Perhaps not. The “bitstreams” processed by Colossus contained impulses that were neither digits nor binary (at least in the sense of the binary number system, though dots and crosses are *binary* in the border sense of a *binary choice*). One might wish that Shannon had been more consistent in his efforts to avoid talking about the transmission of digits. If he had followed through by talking about bandwidth in terms of *binary symbols* or *binary characters* rather than *binary digits* we might now with a clear conscience write about *bicstreams* or measure transmission rates in *bis per second*.

Other scholars applied similar ideas of digital and analog representations to other forms of communication, such as human gestures. For example, in the 1950s the psychiatrists Jurgen Ruesch and Weldon Kees drew on the concepts of *analogic codification* and *digital codification* to categorize different forms of nonverbal communication. They argued that “the use of words, whether in speech or writing, has certain limitations akin to those of digital computers: words remain identifying or typifying symbols.”[14] Later in the same book they suggested that some gestures and facial expressions stood in place of words and hence were recognized as coding distinct meanings.

[14] Jurgen Ruesch and Wheldon Kees, *Nonverbal Communication: Notes on the Visual Perception of Human Relations* (Berkeley, CA: University of California Press, 1956), 8. Haigh learned of this work though a presentation by Luke Stark at the Society for the History of Technology (SHOT) 2018 Annual Meeting, “After the Clinic: Jurgen Ruesch, Weldon Kees, and Cybernetic Non-Verbal Communication, 1950-1960,” St. Louis, MO, 12 October 2018.



In Nonverbal Communication *(1956), Ruesch and Kees suggested that some gestures stood in place of words, and thus were recognized as distinct symbols.*

Decades earlier, as Mara Mills has shown, systems of lip reading had been developed around the use of photographs and drawings to illustrate discrete facial expressions. One system literally digitized sixteen facial expressions associated with speech by assigning a numerical code to each via a “numerical cipher method.”[15]

In this sense, giving a thumbs-up gesture in response to the question “How are you holding up?” is a digital response in that the gesture is intended to be recognized as a discrete symbol (akin to a modern emoji). On the other hand, if someone is asked “How big was the fish?” and responds by holding both palms vertical this is an analog communication: the distance between the palms represents this size of the catch.

Digitally Controlled Machines

The new non-numerical senses of digitality meant that new classes of machine had now become retroactively digital because they were controlled by media that were now recognized as digital even though there were no actual digits involved. Mechanical adding machines and tape-controlled relay

[15] Mills, "Media and Prosthesis: The Vocoder, the Artificial Larynx, and the History of Signal Processing".

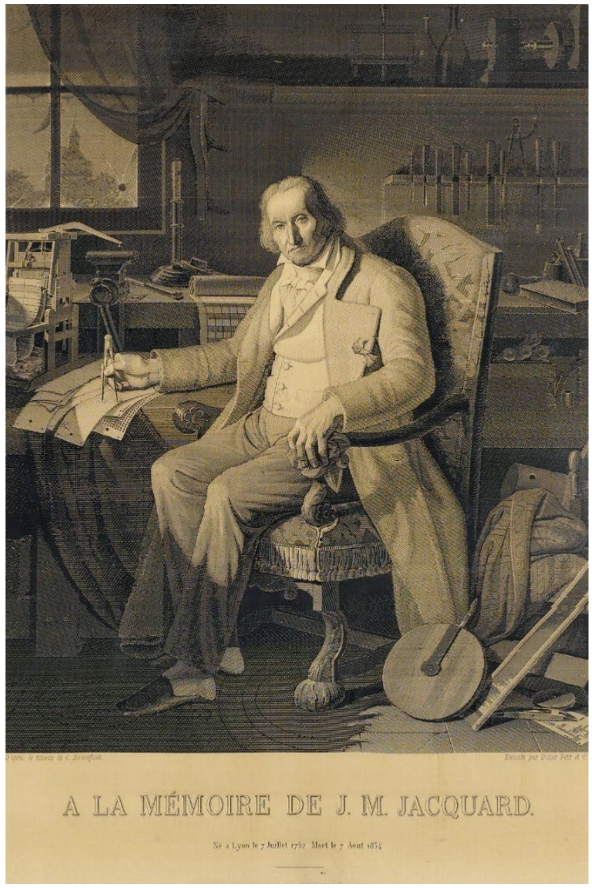
computers had been recognized as digital once the concept of the digital computer was created. Once the Shannonesque senses of digital and analog communication were established, entire families of devices that were not numerical but were controlled by information encoded in discrete forms likewise became retroactively digital. These include player pianos, Jacquard looms, and musical boxes.

The music box is a hybrid of digital and analog. It can play a fix repertoire of notes, corresponding to the fixed symbols encoded on a digital channel. In this case, they are encoded with pins on the surface of a rotating cylinder or disk. Each pin is placed so as to strike a particular cam, which in turn rings a bell or vibrates a prong to produce a fixed note. This is discrete because the position of the pin to strike one or another of the reading mechanisms codes a discrete note. If it was analog then new notes at intermediate frequencies could be produced by moving the pins up or down a little. The theremin, for example, is an analog instrument because the tones it produces vary continuously with movement of the operator's hand. On the other hand, the timing of x ,.j notes is analog. Moving the pin forward or backwards a little will alter the time at which the note is produced by a corresponding amount. Following Shannon, we might call the encoding used in the music box discrete in the dimension of tone but continuous in the dimension of time.

In contrast, Jacquard looms are discrete in both dimensions and hence fully digital – a fact that has led feminist scholars such as Sadie Plant to stress continuities between weaving and programming.[16] The loom weaves each row by attempting to thrust control rods through a punched card. This determines which threads will be woven in that step of the process. Elaborate designs took thousands of cards. In this case the cards are not numerically digital in the same way as the IBM punched cards discussed above were: each position on the card controlled a separate weaving hook but there was no scheme equating different combinations of holes to numerical values. But because it reads its control information in discrete rather than continuous form it is certainly digital in Shannon's broader sense of symbolic digitality. In each of the many cards that are read to weave the design a hole is either present or absent in each position, which corresponds to the threads attached to the corresponding hook being woven or not woven during that step of the process.[17] Just as with the music box, making the hole bigger or smaller or moving the hole to an intermediate position could not produce analogous changes in the colors woven. After one step is woven the loom resets and advances to the next card, thus progressing discretely in the dimension of time.

[16] Sadie Plant, *zeros + ones* (New York: Doubleday, 1997).

[17] Birgit Schneider, "Digitality", in *Textile Terms: A Glossary* (Berlin: Edition Imorde, 2017):71-75.



A finely detailed portrait of Jacquard woven in silk on an automatic loom. The cards that controlled the loom contained a digital version of the portrait in the Shannon sense of encoding a sequence of symbols, but because the cards controlled weaving machinery directly rather than encoding numbers the looms were not digital in the original and more literal numerical sense of digitality.

The woven portrait looks a lot like a digital image, essentially because it is a digital image. Jacquard loom data was very similar to that used in monochrome bitmapped displays, such as those used on the Xerox Alto or early Apple Macintosh models. These machines drove their video displays from a bank of memory chips known as a frame buffer. Each bit in the frame buffer corresponded directly to one pixel on the display. Interpreting patterns as digits would have been meaningless. A bitmapped monochrome image is digital in the symbolic sense, but not in the numerical sense.[18]

Information and Communication

Information theory pioneers such as Shannon and Hamming worked primarily at Bell Labs and were motivated by the potential of digital reading and writing for long distance communication. This drew

---

[18] Color displays are different. Modern color displays use 24 bits per pixel for color information, coding the intensity of red, green, and blue as three numbers each ranging from 1 to 255. Altogether that gives 16,777,216 color variations. Hence the bits within a color pixel do have numerical significance. In contrast, the Jacquard loom image was colored but the picture was created by overlaying a series of single-color images, each coded by one hole position per card.

directly on the wartime involvement of Bell Labs in encryption of digital voice communications. But their concerns and techniques overlapped greatly with those of computer engineers. A digital computer is a network of components in constant communication with each other. As they go about their work digital messages are constantly being encoded, decoded, and transcribed from one medium to another.

Determining the bandwidth of these channels was vital when maximizing the performance of computer designs. In later decades attention would shift to the connection of computers to remote terminals and the development of networks for the exchange of messages between computers. But from the very start, communications processes were vital to electronic digital computing. From this viewpoint, the convergence of computer engineering and digital communications took place in the 1940s, not the 1970s or 1980s.[19] Rather than being a radical discontinuity, one might simply see the development of computer networking as an extension of these connections over longer distances.[20] Conceptually it makes little difference whether information is being communicated over tiny distance, for example within a processor chip, or over long distances, for example with a space probe on the fringes of the solar system. The same digital reading and writing processes that made computer networking possible had been taking place all along within digital computers and between digital computers and peripherals.

The work of Shannon and his colleagues on information theory was central to the early development of what we now call computer science. In most European languages this discipline is named with some variant of the word information: Informatik, l'informatique, and so on. The global organization for computing researchers is called the International Federation for Information Processing. Even in the US, information-centric names were proposed for the field that became computer science and some early programs, such as the Department for Computer and Information Science at the University of Pennsylvania, or the Department of Communication Sciences at the University of Michigan took on names that reflected this heritage. Richard Hamming both chaired the Association for Computing Machinery and was among the first winners of its flagship honor, the Turing Award.[21]

The embrace of information theory by computer engineers was accompanied with a new meaning of the word information, which had traditionally been inseparable from the act of informing: information was only information if somebody was learning something from it. Information was a process, not a thing. When the term "information theory" was attached to Shannon's work this fit with that usage: it explicitly described the transmission of a message from a sender to a receiver, a process during which the receiver was informed. Inside computers, information was constantly being sent and received without human involvement. The various components of a computer system were constantly informing each other as they sent bits back and forth. It took only a subtle slight linguistic and conceptual slippage

[19] Media scholars have been slow to recognize the central importance of the work of Shannon, Hamming, and their colleagues to computer engineering. Bernard Geoghegan, for example, suggested that "When Shannon's theory of communication appeared, it was celebrated but also regarded as a theoretical study of little practical applicability." He suggests that error detecting codes were of merely theoretical interest in the 1950s and were not widely implemented until the 1980s. Bernard Geoghegan, "Information", in *Digital Keywords: A Vocabulary of Information Society & Culture*, ed. Benjamin Peters (Princeton, NJ: Princeton University Press, 2016):173-183, quotation p. 179.

[20] Sebastian Gießmann, *The Connectivity of Things: Network Cultures Since 1832* (Cambridge, MA: MIT Press, forthcoming), chap. 9.

to think of the data stored in computer files as *information* even when it was not being transmitted and received. “Information” became, among other things, a synonym for facts or data – and in particular for digitally encoded, machine readable data.[22] Information became what linguist Geoffrey Nunberg memorably called an “inert substance” that could be stored, retrieved, or processed. We’ve come to think of anything processed by computers as information, creating a new sense of the word that information scientist Michael Buckland dubbed “information as a thing.”[23]

Just as the concepts of information and bits moved from communications engineering to computing, the vocabulary of digital and analog moved the other way, quickly displacing Shannon’s own preferred terms of discrete and continuous. Telephony became a hybrid of analog and digital systems, with analog transmission of voice data down landlines to handsets but increasing reliance on digital exchanges and long-distance transmission of information. Records, conventional television broadcasts, and audio tapes were all analog media, while compact disks, high-definition television, and DAT cassettes were digital. Thus the senses of analog and digital introduced to describe different approaches to the representation of quantities inside computers turned out to have much broader application. While they were still applied most often to different kinds of electronic systems, they apply conceptually to any methods used to encode information.

Conclusion

The historical intersection of digital computers with Shannon’s mathematical treatment of digital communication gave rise to a new sense of digitality. Digital computers were digital because they used discrete methods to represent quantities numerically, that is to say they worked with digits. Analog computers represented quantities by analogy, using continuous variations.

Although the distinction between digital and analog was first made in the context of automatic computers, the concepts were quickly broadened to apply to media and communication systems of all kinds. Shannon’s approach to digitality, or as he put it the transmission of information over discrete channels, was not tied to numbers. The crucial thing was that the message transmitted was coded as a sequence of symbols taken from a fixed and finite set.

Many digital media meet both definitions of digitality, because they turn audio or video data into sequences of numbers and then store the numbers. But not all do, and Shannon’s own examples of textual encoding did not rely on turning the text into numbers before encoding it. In electronic engineering, all systems using logic gates and switching are understood as digital. Once the concept of machines controlled by digital media was created in the 1940s, earlier mechanical technologies, most notably automatic looms, were recognized as having similar properties

Digitality here refers not just to the literal manipulation of information encoded as numbers, but works more broadly to describe all situations in which a part of the world is read by mapping inputs onto one of a fixed, and usually small, number of possible states. These states are often interpreted as symbols. More complex or precise information is encoded and read not by introducing new symbols but by

---

[22] Geoffrey Nunberg, "Farewell to the Information Age", in *The Future of the Book* (Berkeley: University of California Press, 1997):103-138.
[23] Michael Buckland, "Information As Thing," *Journal of the American Society of Information Science* 42, no. 5 (June 1991):351-360.

arranging symbols in sequence. This symbolic, non-numerical digitality underlies today’s digital media. It is to the emergence of the concept of digital storage media that we turn in the next chapter.

Buckland, Michael. "Information As Thing." *Journal of the American Society of Information Science* 42, no. 5 (June 1991): 351-360.

Galison, Peter. "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision." *Critical Inquiry* 21, no. 1 (Autumn 1994): 228-266.

Geoghegan, Bernard. "Information." In *Digital Keywords: A Vocabulary of Information Society & Culture*, edited by Benjamin Peters, 173-183. Princeton, NJ: Princeton University Press, 2016.

Gießmann, Sebastian. *The Connectivity of Things: Network Cultures Since 1832*. Cambridge, MA: MIT Press, forthcoming.

Haigh, Thomas, and Mark Priestley. "Colossus and Programmability." *IEEE Annals of the History of Computing* 40, no. 4 (Oct-Dec 2018): 5-17.

Hamming, Richard W. "Error Detecting and Error Correcting Codes." *Bell System Technical Journal* 29, no. 2: 147-160.

Huffman, David. "A Method for the Construction of Minimum-Redundancy Codes." *Proceedings of the IRE* 40, no. 9 1952): 1098-1101.

Kline, Ronald. *The Cybernetics Moment, Or Why We Call Our Age the Information Age*: Johns Hopkins University Press, 2015.

———. "Cybernetics, Management Science, and Technology Policy: The Emergence of 'Information Technology' as a Keyword." *Technology and Culture* 47, no. 3 (July 2006): 513-535.

Mills, Mara. "Deafening: Noise and the Engineering of Communication in the Telephone System." *Grey Room*, no. 43 (Spring 2011): 118-143.

———. "Media and Prosthesis: The Vocoder, the Artificial Larynx, and the History of Signal Processing." *Qui Parle* 21, no. 1 (Fall/Winter 2012): 107-149.

Nunberg, Geoffrey. "Farewell to the Information Age." In *The Future of the Book*, 103-138. Berkeley: University of California Press, 1997.

Plant, Sadie. *zeros + ones*. New York: Doubleday, 1997.

Ruesch , Jurgen, and Wheldon Kees. *Nonverbal Communication: Notes on the Visual Perception of Human Relations*. Berkeley, CA: University of California Press, 1956.

Schneider, Birgit. "Digitality." In *Textile Terms: A Glossary*, 71-75. Berlin: Edition Imorde, 2017.

Schüttpelz, Erhard. "'Get the message through’: From the Channel of Communication to the Message of the Medium, 1945–1960." In *Media, Culture, and Mediality: New Insights into the Current State of Research*, edited by Ludwig Jäger, Erika Linz and Irmela Schneider, 109-138. Bielefeld: transcript, 2010.

Shannon, Claude E. "A Mathematical Theory of Communication." *The Bell System Technical Journal* 27 (July & October 1948): 379-423, 623-656.

Soni, Jimmy, and Rob Goodman. *A Mind at Play: How Claude Shannon Invented the Information Age*. New York, NY: Simon & Schuster, 2017.

Wiener, Norbert. *Cybernetics, or Control and Communication in the Animal and the Machine*. Cambridge, MA: Technology Press, 1948.

1.3: What's Digital About Digital Media?

Thomas Haigh & Sebastian Giessmann

A modern reader is likely to approach the terms *communication* and *media* through distinct scholarly traditions that have grown up around them. Scholars attempting to establish a science of communication trace their lineage back to the engineering work of Claude Shannon. In a series of seminal articles, Erhard Schüttpelz has shown how the notion of communication emerged out of the applied US war research to become central to information theory, cybernetics, social and anthropological research.[1] One major approach centered on cybernetics and information theory, the other on the study of mass communication and manipulation but both shared the *message* as an organizing concept.

In contrast, media theory takes as its point of departure Marshall McLuhan's 1958 dictum of the medium itself being the message. Yet, argues Schüttpelz, McLuhan and Edmund Carpenter's earlier *Explorations in Communication* had relied upon the paradigm of communication. *Media*, as an analytical category for media studies emerged out of the Toronto School's shared interest in orality and literacy, and its tendency to understand media as grammars of culture.

So what did *medium* mean to the historical actors of the 1940s and the early 1950s? The term comes, of course, from *communication medium* and hence prior to McLuhan's act of appropriation was part of the communications agenda. Yet the term was not as central as *information* or *communication* to Shannon's work, and Shannon preferred the term *channel* to *medium*. From the viewpoint of communications research the crucial technologies of the 1940s were telegraphy, telephony, and radio. All were synchronous and based on the transmission of messages. None involved the storage of information.

In this chapter we explore an alternative thread in the early development of *media* and *medium* as concepts: the origins of the idea of the storage medium in digital computing practices and communities of the 1940s and 1950s. While such practices were obscure at the time, they laid the technological foundation for today's range of digital media. We should say at the outset that digital media do not necessarily use numerical codes. They are digital in the broad non-numerical sense of Shannon's mathematical theory of communication, rather than the narrower and slightly earlier sense of numerical digitality.

Digital Storage vs. Digital Communication

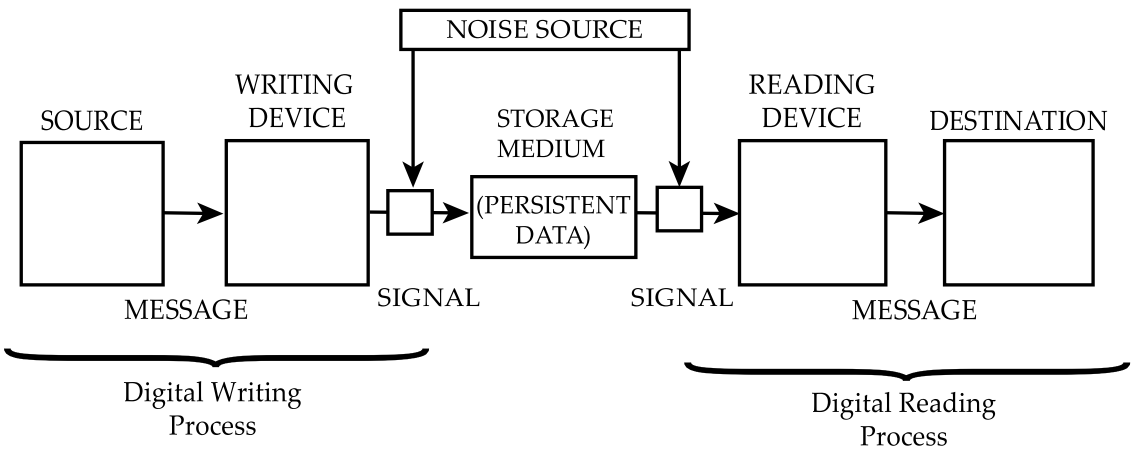
The distinction between digital (storage) media and digital communication, if such a distinction can be meaningfully made, is one of temporality. The system described by Shannon, in which the signals read digitally by the receiver were deliberately encoded and placed into a channel with the intention that they be immediately received and recoded, describes a special case of digital writing and reading. This model, based more than anything else on the practices of telegraphy, is most directly applicable to synchronous communication. A human operator taps out the message as a series of letters expressed in dots and dashes. The receiver transcribes the letters as they are received. The temporalities of sending

---

[1] Not all of them have been translated, alas. We already made reference to Erhard Schüttpelz, "'Get the message through': From the Channel of Communication to the Message of the Medium, 1945–1960", in *Media, Culture, and Mediality: New Insights into the Current State of Research*, ed. Ludwig Jäger, Erika Linz, and Irmela Schneider (Bielefeld: transcript, 2010):109-138.

and receiving are synchronized. This does not mean that communication is instantaneous. Even electrical impulses are not truly instantaneous, and transcription may lag slightly behind transmission. In telegraphy information placed into the channel is not persistent. The receiver must match the pace of the sender and either note down or mentally buffer symbols as they are transmitted.

The temporalities of digital storage media were more complex. Early computer systems applied digital reading and writing practices to media such as punched cards, magnetic tape, magnetic disks, and paper tape. All these media were stable: digital sequences written to them would persist indefinitely and could be read repeatedly as required. Other media, such as mercury delay lines and cathode ray storage, retained information for very short periods which necessitated a constant process of reading and rewriting the symbols stored in them to preserve information from one minute to the next.



A reinterpretation of Shannon's model, in which the central box represents a digital storage medium such as a punched card deck or paper tape. Reading and writing processes occur in the same way as the standard model, but at different times.

Shannon had produced a theory of communication, not a theory of storage media. But with one minor adjustment his model fit perfectly with digital storage technologies. Imagine that instead of transmitting each symbol immediately to the received, the channel instead buffers the sequence of symbols for later retrieval. There is still a sender, a receiver, a process of encoding, and a process of decoding. But the message sits in the channel until the receiver is ready. Because the processes of reading and writing occur asynchronously, the channel of digital communication has become a medium for digital storage. Only then does the apparently confusing pairing of the static *storage*, a container in which something rests, make sense in conjunction with the active *medium*, the infrastructure through which messages move.

An example will make this less abstract. From the 1940s to the 1970s many computer systems used punched cards as a medium for the temporary storage of input data and program code. The source of the data was a person reading information from forms. The writing device was a key punch. The storage medium was a deck of punched cards in which the sequence of coded symbols keyed by the key punch operator accumulated. Eventually the deck of cards is mounted in a reading device and read digitally to reproduce the same series of coded symbols in a different medium. Early punched card readers used mechanical brushes to sense the presence or absence of holes in each position, later models were able to read more than a thousand cards a minute using photoelectric sensing. In either case, the reading process transcribed the bits from cards into electric impulses flowing down wires. The process would repeat inside the computer, where these impulses were read and transcribed into electronic storage.

The practice of storing encoded messages also has its roots in telegraphy, where paper tapes were used to record messages, and in some cases to transmit at high-speed messages punched onto tape in advance. For example, the German network of encrypted radio teleprinters targeted by the British Colossus devices could be used to transmit messages stored on paper tape. The same five track paper tape was a popular recording medium for the computers of the early-1950s, a cheap and readily available method of getting programs and data into computers and results out. We may distinguish further here between inherently persistent media like computer tape and those that must constantly be automatically read and rewritten to achieve temporarily stability such as a mercury delay line, cathode ray tube storage, or later a dynamic RAM chip. There are likewise differences in the affordances of purely sequential media such as tape and random-access media such as disks and core memory, and between media such as punched cards and paper tape that can be written only once, and those such as magnetic tape that can be overwritten.

In this conception the storage medium replaces the unlabeled central box that in Shannon's standard model represents the communication channel. The medium is, essentially, a buffer between the transmitter and receiver. But it is also possible to view the same process as two distinct processes of communication using Shannon's standard model. The storage medium is the destination of the first act of communication, representing digital writing. It is the information source of the second act of digital communication, representing the process of digital reading.

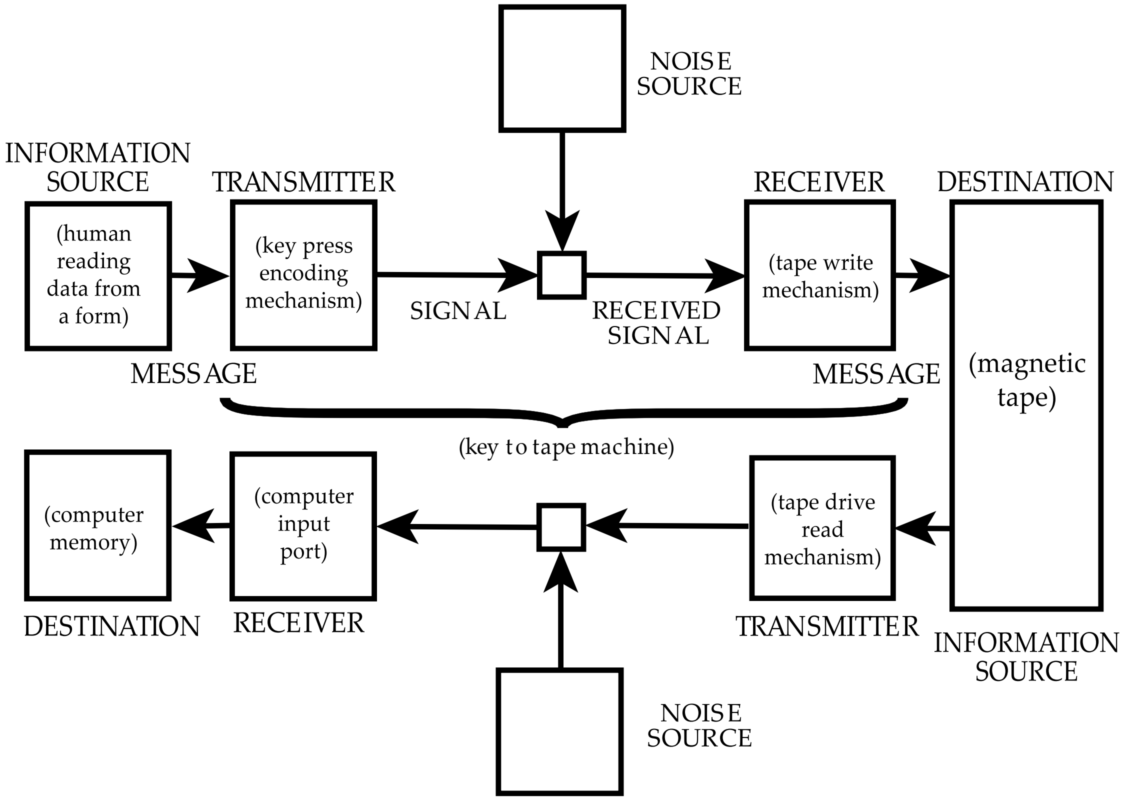
Such processes occur constantly within digital computers, involving the transmission of coded messages between non-human actors. A processor communicates a string of symbols to the mechanism of a card punch; a magnetic tape drive reads codes and sends them along a wire as encoded impulses to the processor which reassembles them in a register; characters are transcribed from main memory into a register, which immediately switches from receiver to sender and copies them down a different wire leading to a printer. In each of these cases a message is passed from a sender to a receiver, it's just that both are mechanisms.

Again, an example makes our point clearer. Consider a process of data entry onto a computer as it might have been practiced in the late-1960s using a *key to tape* device. This replaced the key punch unit, logging keystrokes from an operator directly onto a reel of magnetic tape. The same reel was later mounted in a tape drive connected to a computer, from which chunks of data were read sequentially into the computer's processor.

A key to tape unit, introduced by Mohawk Data Systems in 1965.[2]

In the diagram below the process is represented by two interlinked copies of Shannon's classic diagram. The first act of digital communication occurs inside the key to tape machine, as key presses are coded into electric impulses received by the tape mechanism and written onto the tape. The second act of digital communication occurs when the same tape, which is now the source rather than the destination, is read in a tape drive. Signals travel over a cable, are received by the input/output hardware of the computer and finish up transcribed into electronic memory of some kind (probably an input register).

[2] https://georgecogar.com/2016/05/15/mds-1101-brochure/#jp-carousel-233



Each act of digital reading or digital writing can be conceived as a distinct communication process using Shannon's original model with no changes.

The two examples given above are functionally equivalent: data moves from paper into a computer via an intermediate medium. The first diagram conceptualizes this as a single asynchronous act of message transmission in which a storage medium replaces Shannon's channel. In Shannon's model a communications channel has a storage capacity of just one symbol which must therefore be received as it is being transmitted. Digital reading and writing are therefore synchronous. Increasing that storage capacity by replacing a punched card deck or magnetic tape changes the temporality of communication. Reading and writing occur asynchronously. One might conclude that a communication channel is just a storage medium with a very small capacity. Yet, as the second diagram shows, is just as informative to conceptualize the same example as describing two synchronous processes of communication each involving digital reading and writing. The acts of digital reading and writing in the first diagram each decompose in the second to become entire processes of communication including both reading and writing. The second diagram could be further decomposed into more distinct acts of communication by following the progress of the bits though the computer's input circuits and via the main processor or an auxiliary processor, though one or more registers, and eventually into main memory. We conclude that the distinction between digital communication and digital media is a matter of perspective and temporality.

Digital Storage in Early Computing

This mapping of the technical processes of early electronic computing onto Shannon's model of communication might seem like an empty exercise. But in fact it illustrates the applications for which the ideas of Shannon and his fellow information theorists were most immediately and profoundly relevant. Having established the equivalence of storage and communication in this context, we will look more closely at the context of data storage in early digital computers. The language of media, mediation, and symbol processing was central to technical conceptions of modern computing from the very beginning for the very pragmatic reason that these concepts were vital in the design of functioning computer systems.

Most of the electronic digital computers built in the late-1940s and early-1950s employed several media to store and process both numbers and instruction codes. The majority of early US computers, including commercial models, were based on the design produced by John von Neumann's team at the Institute for Advanced Study at Princeton. That was a refinement of von Neumann's original description of the modern computer, the 1945 *First Draft of a Report on the EDVAC*, in which these media constituted two distinct "organs" of the machine: organ M for memory, the high-speed electronic storage used for the program instructions and data currently being processed which "requires perfectly distinct and independent registration and storage of digital or logical symbols" and organ R for recording, the slow but persistent medium used to load programs and data into memory and store the results of the computer's work. Von Neumann called organ R "the natural medium for long time storage of all the information obtained by the automatic device on various problems."[3] This organ was, in his terminology, "outside" the computer proper, so that operations of "input and output" would be "mediating the contact with outside." This distinction would appear to be the origin point for the now ubiquitous concepts of computer storage and of input/output.

Both storage and memory organs were essential to any useful digital computer. Every computer was coupled with at least one device able to read and write digitally to a permanent storage medium. Early systems used paper tape, punched cards, or magnetic tape for this purpose. Programs to be run were transcribed from this medium into a high-speed addressable memory: a delay line, a Williams tube, a Selectron tube, a rotating magnetic drum, or core memory. The instructions currently being executed and the numbers currently being manipulated were copied again, into register storage (a small amount of high speed memory inside the central processor, built using vacuum tubes).

We will not describe at length the many different objects that were manipulated to store bits and read to retrieve them; suffice it to say that the mechanisms used were varied and ingenious. Running even the simplest program required many operations to transcribe bits between these media, during which they were transiently embodied in yet other forms: electric pulses conducted by wires, electromagnetic waves picked up by read heads, or the motion of rods punching through card. Bits moved within and between these computers and their peripherals as digital messages of exactly the kind discussed by Shannon, each wire a communications channel. Determining the bandwidth of these channels was vital when maximizing the performance of computer designs.

The major challenges involved in building a usable digital computer centered on perfecting these mechanized practices of digital reading and writing. Both candidate memory technologies, cathode ray tubes and mercury delay lines, required lengthy periods of experimentation to become functional.

[3] John von Neumann, "First Draft of a Report on the EDVAC," *IEEE Annals of the History of Computing* 15, no. 4 (October 1993):27-75. The comment on "mediation" is a section heading for 2.6. The quote on a "natural medium" is from section 2.9. Note that von Neumann's mention, in section 12.8, of the memory storing "digital or logical symbols" aligns with the initial, literal sense of digitality as applying only to representations of digits.

Magnetic tape, the highest performance medium for long term storage, was also challenging. Between them these accounted for most of the challenges that delayed early computer projects, such as von Neumann's own computer at the Institute for Advanced Studies or the commercial Univac effort, years beyond their original schedules.

As Mara Mills has noted, "Although a growing scholarly corpus has now demonstrated the materiality of electronic/digital/computerized media, most authors continue to attribute a fantasy of disembodied communication to early cyberneticians and electrical engineers."[4] The historical record amply disproves this fantasy. Bell Labs studied information for the benefit of engineers, not cultural theorists. During the late-1940s and early 1950s the community of engineers involved in building computers and storage devices were the earliest and most enthusiastic adopters of information theory, because they were the community charged with figuring out rapid and reliable ways of making digital communication work. These acts of communication were not primarily between humans but between mechanisms, occurring constantly between a computer and its peripherals and within the different parts of the processor itself. Their creators adopted the vocabulary and practices pioneered at Bell Labs: bits, bandwidth, parity, coding schemes, error correction and detection, redundancy, and information. They relied on the techniques described by Shannon and his colleagues to make these enormously complex machines function reliably, for example by introducing redundancy when storing messages on tape so that errors could be detected.

Alphabets are Digital

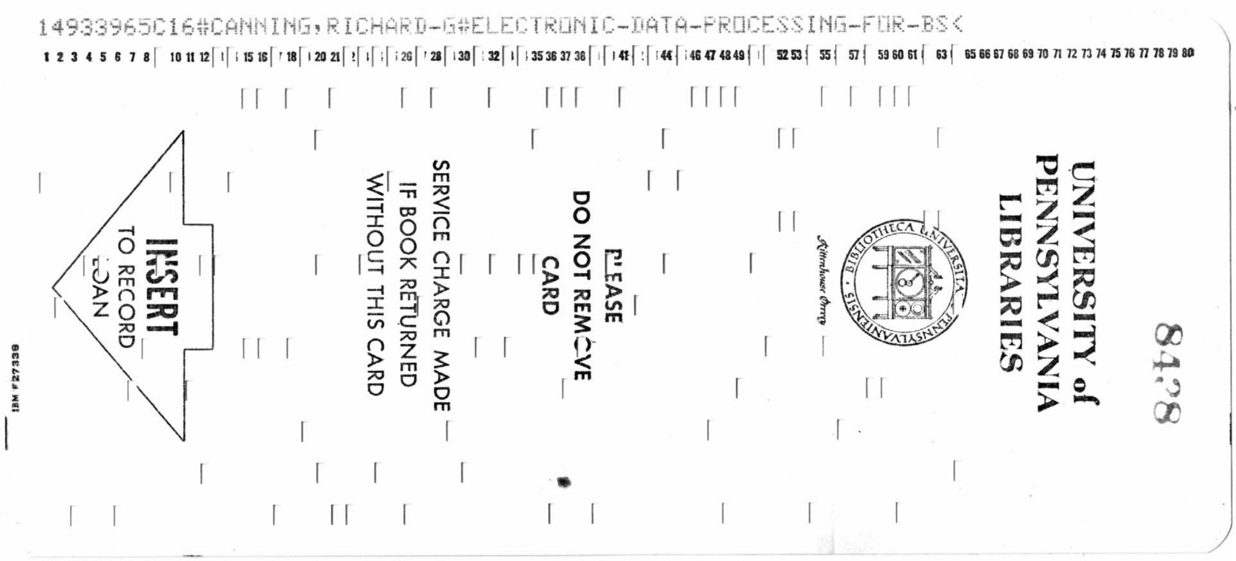
Shannon's reliance on textual examples raises the question: is text expressed in an alphabet always digital, or is it digital only when stored in computer readable form? Is a conventional printed book a digital storage medium? The answer depends on one's definition of digitality. According to the numerical sense of digitality, texts become digital only when transposed into numbers. In the Shannon-influenced, symbol-oriented sense of digitality, text has always been digital. Arabic numerals provide 10 symbols while the English alphabet provides 26 letters. Combine those 36 characters with upper- and lower-case variants, punctuation, and other symbols and one might use six, seven, or eight bits to code a full set of symbols. [5] Unicode, intended to cover the needs of writing systems such as Braille, Old Persian, and kanji as well as Western European alphabets, uses up to 38 bits per character in its most common format. But even that large set of symbols is most definitely finite.

This was recognized in practice long before Shannon formalized his theory of communication. We already discussed the original use of punched cards to represent digits. By the 1930s, however, IBM realized that it could extend its standard 80 column card format to represent text as well as numbers. There was, as in the card we saw earlier, room for 12 rows of punch positions. With the two extra rows, and by building equipment to recognize all possible combinations of a punch in one of the top three rows combined with a punch in one of the lower nine rows, IBM increased the number of character

[4] Mara Mills, "On Disability and Cybernetics: Hellen Keller, Norbert Wiener, and the Hearing Glove," *differnces* 22, no. 2&3 (2011):74-111, quote p. 78.

[5] Encoding and mechanically processing the character sets used by other languages was vital to the global spread of information technology. It poses a challenge not just for internal representation, but also for data entry via keyboards. Chinese text, in particular, was often mapped onto representations coded in Latin alphabets. Thomas S. Mullaney, "QWERTY in China: Chinese Computing and the Radical Alphabet," *Technology and Culture* 59, no. 4 (October 2018):S34-S65.

codes from 10 to 39. That was enough to represent all the upper case letters and digits, with three codes left over for &,-, and /. [6]



This IBM card was stored inside the cover of a library book to speed the checkout and return process. It encoded text as well as numbers on a card format originally designed to store 80 decimal digits, by using two extra rows at the top of the card and giving a unique meaning to every combination of a punch in one of the top three rows with a second punch in one of the nine lower rows. Printed text at the top duplicated this information in alphanumerical characters, a digital representation read more easily by humans.

Text is most certainly not analog: an alphabet provides a fixed set of characters rather than a continuous range in which one letter blends into another. The philosopher Nelson Goodman recognized this in his 1968 book *Languages of Art: An Approach to A Theory of Symbols.*[7] Goodman defined languages as "symbol systems." Their characters could, as in typography, be written in many different ways as long as readers could reliably distinguish all the equivalent marks as representations of the same character. Characters must be disjoint, represented in ways clearly distinct from each other with "a wide neutral zone" between them. Goodman called this principle "finite differentiation." According to Goodman, "the syntactic requirements of disjointness and finite differentiation are met by our familiar alphabetical, numerical, binary, telegraphic, and basic musical notations."[8]

Goodman went on to connect his ideas to the concepts of analog and digital, reflecting the evolution of these categories away from their original roots when he wrote 'Plainly, a digital system has nothing to do with digits, or an analog system with analogy." His analysis echoed Shannon's conception of coded symbols. It was, essentially, that analog systems provide an undifferentiated range of markings, which

---

[6] Once computers arrived, IBM added a "binary" card format that used all possible combinations of punches, effectively coding 4096 possible symbols in each row. This was far more efficient, but the volume of punching tended to cause both cards and card processing equipment to fall to pieces.

[7] Nelson Goodman, *Languages of Art: An Approach to a Theory of Symbols* (Indiannapolis, IN: Bobbs-Merrill, 1968).

[8] Ibid.., 132-140. Quotation is from p. 140.

are "the very antithesis of a notational system…. A digital scheme, in contrast, is discontinuous throughout."[9]

We earlier suggested that digits written on a piece of paper must be considered digital, according to any reasonable definition of the term. But by the broader definitions of digital, which encompass all sequences of symbols rather than just sequences of digits, we must also recognize text as digital when printed on paper, or even when written by hand. To type a manuscript into a word processing program is not an act of digitization or analog to digital conversion; it is a transcription from one digital notation to another.

Being digital does not necessarily mean that a medium is machine-readable, nor that it cannot be read by humans. What is, or is not, machine readable will in any event change with time. In the 1950s, for example, a project was launched to print account and routing numbers onto checks in a format readable both by humans and by computerized check clearing systems. That was realizable at the time only by writing the numbers in magnetic ink, using a highly stylized font that looked odd but recognizable to human eyes. By the 1990s, neural networks developed at Bell Labs could reliably read handwritten numbers to automatically process the amounts written in pen on checks as well as the codes printed in magnetic ink.

It's a matter of historical record that nobody called text "digital" before the invention of the modern computer. Thinking of characters as well as numbers as "digital" reflects both the influence of Shannon and the reality of digital computers that used numbers to encode and process text. Seeing text as digital is thus a backward projection of categories. Yet once the categories are established there seems no plausible reason to deny that the alphabet was, in the modern sense, always digital.

The Interchangeability of Digital Representations

The idea that "the digital" is defined by its immateriality is both ridiculous and common, a combination that calls out for substantial historical and philosophical analysis. Yet there is something special about the relationship of bits to their material representations: different material representations are, from a certain viewpoint, interchangeable. The same sequence of symbols can be read from any of them. As Matthew Kirschenbaum has argued:

> two properties of digital computation—its allographic identity conditions and the implementation of mathematically reliable error detection and correction—are what ultimately account for the immaterial nature of digital expression. My point is not that this immateriality is chimerical or nonexistent, but rather that it exists as the end product of long traditions and trajectories of engineering that were deliberately undertaken to achieve and implement it.[10]

Analog representations of information could also be converted from one form to another. Mara Mills has explored analog technologies developed to transform audible speech into visual representations (sound spectrographs and audiograms) and tactile sensations (the so-called *hearing glove*).[11] But these

---

[9] Ibid.,160-161.

[10] Matthew Kirschenbaum, *Mechanisms: New Media and the Forensic Imagination* (Cambridge, MA: MIT Press, 2007), 137.

[11] Mills, "On Disability and Cybernetics: Hellen Keller, Norbert Wiener, and the Hearing Glove", Mara Mills, "Deaf Jam: From Inscription to Reproduction to Information," *Social Text*, no. 102 (Spring 2010):35-58, Mara Mills,

conversions were approximate and ambiguous. In contrast, digital information can be copied from one medium to another without any loss of data, and the same sequence of symbols can be recovered from each. Transcribe the text of the book into a text file, save that file, compress it, email it, download it, decompress it, and print it out. The different representations have different affordances and must be read in different ways. Yet each can be read in a way that produces the same sequence of symbols.[12] Discussion of "digital formats," vague as it often is, gestures towards the truth of this experience: digital content can be downloaded over a network and, if sufficient bandwidth is available, experienced just as if it had been accessed from a local disk. "The real virtues of digital instruments," Goodman insisted, "are those of notational systems: definiteness and repeatability of readings."[13] As the information is constantly and automatically transcribed and transcribed from one digital representation to another it is easy to lose track of its materiality entirely and assume that it really does live in an immaterial cloud of data floating somewhere in the heavens.

What we call the *interchangeability of representations* has been called *cultural transcoding* by Lev Manovich. In his *Language of New Media*, transcoding figures prominently as the fifth, and most important principle of new media. It builds upon the four preceding principles of numerical representation, modularity, automation, and variability. "In new media lingo," Manovich writes, "to 'transcode' something is to translate it to another format." While making representations interchangeable, digital computation affords for the astonishing variability in media practices that Manovich maps. To Manovich transcoding is what is turning the computer into a media machine that turns slightly older media into computer data. [14]

Different material representations of the same text are only interchangeable from certain viewpoints, and for certain purposes. A book is not the same thing as a text file stored in memory, which is not the same thing as a compressed file on a hard disk. The printed text would differ materially depending on whether one used a dot matrix printer or a modern laser printer. Neither would replicate the original book. For one thing, any illustrations or annotations would be lost, as would the possibility of studying the book to learn details of the process by which it had been printed or the history of typography. Likewise, two performances of the same musical score are not identical, however talented and careful the musicians. If blessed with superhuman abilities one might listen to the performance of a musician and write out the corresponding score. The two scores and the performance can all thus be read digitally as interchangeable representations of the same sequence of coded symbols. Yet no two performances are exactly alike – a fact that for decades kept the classical music industry busy creating and selling new recordings of old works. To interpret a score the performer adds a great deal that is not written on the page.

"Deafening: Noise and the Engineering of Communication in the Telephone System," *Grey Room*, no. 43 (Spring 2011):118-143.

[12] Kirschenbaum offers a longer and more worked through discussion of the possible sequence of representations and translations a text might go through in the process of composition in Matthew G Kirschenbaum, *Bitstreams: The Future of Digital Literary Heritage* (Philadelphia, PA: University of Pennsylvania Press, 2021), 1-5

[13] Goodman, *Languages of Art: An Approach to a Theory of Symbols*, 161.

[14] Lev Manovich, *The Language of New Media* (Cambridge, MA: MIT Press, 2001), 45-47.

Goodman suggested that this interchangeability across physical representations was an inherent feature of notational systems. Drawing on an interest in visual art, he pointed out that paintings can be faked but poems can't, because the same poem might be written out by hand or printed in different styles on different kinds of paper. "All that matters is what may be called sameness of spelling: exact correspondence as sequences of letters, spaces, and punctuation marks."[15] Musical scores use a different system of notation which, from Goodman's viewpoint had the same fundamental characteristics. He called systems of this kind "allographic," the term invoked by Kirschenbaum above as a key characteristic of digital representations, unlike "autographic" works such as paintings where any copy differs from the original in fundamental ways.

Many readers might indeed view a handwritten manuscript, a typewritten page, a plain text computer file, a magazine publication, or a printed volume using one of a variety of unremarkable typefaces as all constituting authentic representations of the same poem, even if they preferred the aesthetics of one or another format. However, Kirschenbaum has recently given two examples that implicitly challenge Goodman's assertion that poetry relies only on the affordances of text and punctuation symbols. Both poets made use of the affordances of early Apple Macintosh personal computers. William H. Dickey used the HyperCard authoring tool to produced fourteen "HyperPoems" that mix text with graphics and react to each readers' mouse clicks. Edward Kamau Braithwaite published his poems on paper, but their meaning is conveyed in part by the aesthetics of custom screen fonts that pixelated heavily when resized on his early Macintosh. Some editions sacrificed much of this typography, but Kirschenbaum insists that even minor changes inherent in the publishing workflow "would invariably compromise the original integrity of the work."[16] This is not, however, to say that the text used in more conventional poems is not digital. Rather, some poets have produced work that requires far more complex (and unstable) platforms of digital representation than plain text to faithfully distribute. Braithwaite used a digital computer to produce work that could, at the time, be redistributed only by the analog process of photographing his original printed manuscripts onto film.

Kirchenbaum's examples highlight the extent to which media from which the same sequence of symbols can be read are interchangeable for some purposes, or for some readers, but not for others. For applications where typography matters one might, as some manuscript preservation programs do, deal with this by making an extremely high resolution scan of the book rather than transcribing the text into a computer file. That would produce an entirely different digital representation of the same object, and one that might serve the needs of more kinds of readers. But even that would not substitute for the all the uses of the original. In this context, Anthony Grafton invoked the story of a researcher who traced the spread of cholera by sniffing letters, to see which had been perfumed with vinegar before sending (vinegar having, allegedly, been believed to prevent the spread of the disease).[17] More prosaically, a printout would be more suitable than the a file on a USB stick suitable for lighting a fire with.

Digitality is in the Ear of the Beholder

[15] Goodman, *Languages of Art: An Approach to a Theory of Symbols*, 115.
[16] Bitstreams, p 64, ch. 2.
[17] Anthony Grafton, "Further Reading: Digitization and its Discontents," *The New Yorker,* November 5 2007. He took the story from John Seely Brown and Paul Duguid, *The Social Life of Information* (Boston: Harvard Business School Press, 2000).

The fact that we can write on, print on, draw on, or punch an IBM card provides a nice illustration of a more general truth: digitality lies not in an object but the way the object is read. We might, for example, admire the position of the holes on a punched card as a piece of abstract art, reading them in an analog fashion. Plenty of people enjoy the aesthetics of tattoos written in characters they cannot read. They appreciate them as brush strokes and shapes. We sometimes admire characters we can read in a similarly abstract manner, coveting the shape of a letter in a particularly handsome typeface.

The same is true of other media. A cassette recorder is itself neither digital not analog. I (Haigh) have in my lab a beautifully engineered Sony audio cassette recorder that I have used to record hundreds of hours of oral history interviews. The only digital thing in it is the tape counter. My microphone turns fluctuations the volume of sound into fluctuations in electric current; the tape write head turns those into magnetic fields which in turn realign particles the tape as it passes underneath it. The amplitude of the sound, the resistance, the current, and the magnetic field are all analogous to each other. When I play a tape back the process reverses: magnetic field to electricity to sound. The stored sounds of the interview fill the air. Yesterday I plugged the headphone jack of the same tape recorder into an Acorn BBC Microcomputer manufactured in 1982. I placed a standard audio cassette labelled *Rocket Raid* into the player, entered *TAPE followed by CHAIN "" on the computer keyboard, and pushed play. Played on a speaker, the tape yields a series of atonal warbles and howls separated by short intervals of silence. That's the analog interpretation, something a music critic might approach as an experimental work akin to Lou Reed's inscrutable *Metal Machine Music*. Read digitally by the appropriate control circuits and algorithms, rather than turned into vibrations in the air and my inner ear, the same oscillations were instead read as a series of digitally coded symbols that eventually loaded about 12 kilobytes of data into the computer's sadly limited RAM. Having counted its progress block by block, after about five minutes the computer sprang suddenly to life and offered me a passable imitation of the arcade classic *Scramble*. Digitality is not in the tape itself, nor anywhere in the tape player, but in the reading of the output of the tape player. (Fax machines and modems used similar techniques to read and write digital data as electrical oscillations that could make their way reliably over telephone lines optimized for analog voice signals).

I could have loaded the same game in a few seconds from a floppy disk, another process of magnetic reading, or from the Gotek floppy emulator next to it which would have fetched the same sequence of bytes from a flash memory chip. Each medium can be read to produce the same sequence of symbols and hence put the same bytes into the same memory locations, but very different in affordances such as speed, cost, random access, reliability and so on. Just like my tape recorder, disk drive controllers perform a similar conversion of analog signals produced by magnetic read heads into patterns of encoded bits.

That's true of hard as well as floppy disks. In early personal computers, such as the IBM PC XT, the hard drive itself output analog signals just like my tape recorder. [18] The job of turning them into bits and bytes was the responsibility of the controller card, plugged into the motherboard at the end of a long ribbon cable. Upgrading the stock IBM controller card with a replacement that used a more efficient system of encoding (RLL rather than MFM) could upgrade the capacity of the XT's standard 10MB drive to 15MB,

[18] The technologies of hard disk drive recording were given a thorough examination in Kirschenbaum, *Mechanisms: New Media and the Forensic Imagination*, 86-96.

though every sector of the disk would have to be demarcated anew on its surface, in a "low level format" that took hours to complete.

Conclusion

To reiterate the main themes of this chapter, the concept of a digital storage medium is as old as the digital computer itself and is central to the possibility of its existence. Digital storage is digital in the same sense that digital communication is digital, i.e. because it involves the reading and writing of coded symbols, no the literal reading and writing of digits. Yet digitality is a feature of the practices used to read and write symbols from a medium, not a physical property of the medium itself. Because different digital reading practices can be used to reliably extract the same sequences of coded symbols from entirely different media, we say that those different representations are interchangeable. For example, a printed book and a Project Gutenberg text file held on a hard disk drive can each be read to produce exactly the same sequence of characters. Of course, any object can be read in many different ways, so for other purposes the two representations will not be interchangeable.

As Kirschenbaum observed, because many kinds of digital reading processes take place on scales invisible to the human eye, and because processes of automatic digital reading and writing are often coupled to constantly and invisibly transcribed symbol sequences between media, these affordances of digitality can create the illusion of immateriality. Redundant digital encodings that allow the recognition and correction of errors improve the reliability of digital reading and the creation of perfect copies. Modern digital media technologies read and write information in forms invisible to human senses: radio waves, light pulses, flash memory cells packed together on a microscopic scale, electrical impulses, or magnetic bands. Information is always material, in that it consists of symbols read digitally from one or another corner of the physical universe. But when it is being transcribed so rapidly and automatically from one representation to another we lose track of that materiality.

Brown, John Seely, and Paul Duguid. *The Social Life of Information*. Boston: Harvard Business School Press, 2000.

Goodman, Nelson. *Languages of Art: An Approach to a Theory of Symbols*. Indiannapolis, IN: Bobbs-Merrill, 1968.

Grafton, Anthony. "Further Reading: Digitization and its Discontents."*The New Yorker*, November 5 2007.

Kirschenbaum, Matthew. *Mechanisms: New Media and the Forensic Imagination*. Cambridge, MA: MIT Press, 2007.

Kirschenbaum, Matthew G. *Bitstreams: The Future of Digital Literary Heritage*. Philadelphia, PA: University of Pennsylvania Press, 2021.

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

Mills, Mara. "Deaf Jam: From Inscription to Reproduction to Information." *Social Text*, no. 102 (Spring 2010): 35-58.

———. "Deafening: Noise and the Engineering of Communication in the Telephone System." *Grey Room*, no. 43 (Spring 2011): 118-143.

———. "On Disability and Cybernetics: Hellen Keller, Norbert Wiener, and the Hearing Glove." *differnces* 22, no. 2&3 2011): 74-111.

Mullaney, Thomas S. "QWERTY in China: Chinese Computing and the Radical Alphabet." *Technology and Culture* 59, no. 4 (October 2018): S34-S65.

Schüttpelz, Erhard. "'Get the message through': From the Channel of Communication to the Message of the Medium, 1945–1960." In *Media, Culture, and Mediality: New Insights into the Current State of Research*, edited by Ludwig Jäger, Erika Linz and Irmela Schneider, 109-138. Bielefeld: transcript, 2010.

von Neumann, John. "First Draft of a Report on the EDVAC." *IEEE Annals of the History of Computing* 15, no. 4 (October 1993): 27-75.

What's Digital about Algorithmic Control?
(first chapter for part 2)

In the first part of this book we explored the origins of digitality as a concept in the 1940s, stressing its evolution from a concept focused narrowly on the encoding of digits to a broader category covering the communication and storage of discrete symbols of all kinds. While we explored the ways in which earlier information technologies such as punched cards, automatic looms, music boxes, written text, and even hand gestures were retroactively classified as having been digital all along it was hard to separate this discussion from the digital computer. As well as inspiring the original separation of digital and analog approaches towards the representation of information, the computer was an early and extremely important venue for the refinement and application of digital communication techniques and for the development of digital storage media.

We tried to walk a line between acknowledging the importance of computers to the historical emergence of digitality and de-exceptionalizing computer technology. This approach emphasizes the digitality of the digital computer and its kinship with other kinds of digital reading. So much discussion today equates digitality and computers, as if the dividing line between digital and analog is whether something exists inside or outside of a computer system. In contrast, we argued for symmetry: the reading practices that define digitality can be carried out in just the same way by humans or by machines. Text printed in a book or punched onto paper tape is no less digital than text held on a USB stick. Digits written on a piece of paper are still digital, even though they can be read by an unaided human as well as by a modern smartphone. The automated processes of constant digital communication that constantly shuffle bits back and forth between different material representations inside a digital computer occur on a spectacularly different scale from the human working with pen and paper, but are not fundamentally different. Alan Turing, for example, grounded his abstract treatment of automatic computation in the imaginary mechanization of the work carried out by a clerk equipped with a pencil.[1]

Yet we must also admit that digital computers introduced their own powerful affordances. Here, and in my work with Mark Priestley, we emphasize the centrality of developments in digital reading and writing to the feasibility of modern digital computers.[2] Programmable computers were made possible by the mechanization of digital reading and writing but greatly extend its flexibility. The fundamental affordance introduced by the programmable computer is *algorithmic control*.

Programming Machines

We did not yet discuss the concept of a computer program. In our view, programmability is a general concept not limited to electronic computers. Historically, the term program was adopted by early computer groups, including the ENIAC team, with something very close to its everyday meaning as expressed in concepts such as a lecture program, concert program, or degree program. In each case, a program defined the things that would happen and the order that they would happen in.

Messages can, of course, control as well as inform – an idea at the heart of cybernetics ("control and communication in the animal and machine" was the subtitle of Weiner's book). Because digital

---

[1] The connection of Turing's work to bureaucracy is explored in Jon Agar, *The Government Machine: A Revolutionary History of the Computer* (Cambridge, MA: MIT Press, 2003), 69-74.
[2] Mark Priestley and Thomas Haigh, "The Media of Programming", in *Exploring the Early Digital*, ed. Thomas Haigh (Cham, Switzerland: Springer, 2019):135-158.

encodings can be read reliably and precisely they are exceptionally well suited for control purposes. As an automatic computer begins work its instructions, in some medium or another, are present within it. Otherwise it could not shift automatically from each to its successor. As von Neumann put it in the 1945 *First Draft of a Report on the EDVAC*, which for the first time set out the core architectural features of the modern computer, "These instructions must be given in some form which the device can sense." While he referred to this storage as involving "the use of some code" he applied the concept broadly, to include punched cards, paper tape, magnetic storage, photographic film, and wires arranged in a plug board. The modern computer, then, was first conceived with a full panoply of digital media usable for control purposes: optical, magnetic, wired, and physically sensed.[3]

In that sense any machine whose operation is controlled by digital reading practices is executing a program. A player piano, for example, executes a program of musical notes based on the holes punched in its control tape. From today's viewpoint, saturated by cultures of computation, media scholars might argue about whether the symbols punched onto cards to encode census returns or read from a continuous stack of paper cards to drive an automatic loom are programs or data. It is more intuitive to interpret the coded census returns as data, since we can imagine that the program to tally them is embedded in the framework of the tabulating machine. Conversely, because the holes in the cards controlling the loom control the operation of the weaving machine it is common to call them a program. Yet in fact both do exactly the same thing: the presence or absence of a hole directs a piece of machinery. In fact, any mechanized process of digital reading must control some piece of machinery by switching it to one of several possible states. A distinction between program and data exists in our minds, but not in the minds of the people using these technologies in the 1890s or in any aspect of the machines themselves.

A computer, or to use the vocabulary of the 1940s an *automatic digital computer*, is a device that performs a series of mathematical operations over time. As I have argued elsewhere, the very concept of a computer program is fundamentally digital, in the broad sense of discrete rather than the narrow sense of numerical.[4] A digital computer, unlike an analog computer, breaks up its work into a series of distinct operations. Its program specified which operations it should perform and in what order, just as a concert program specifies which musical pieces an orchestra will perform and in what order.

The most powerful digital computers completed before 1945, like the Harvard Mark 1 and Konrad Zuse's early relay computers, were controlled by input tapes. In that respect they resembled the Jacquard looms and player pianos that we discussed previously as examples of non-numerical machinery controlled by digital reading processes. They were just player pianos that performed mathematics rather than music. Any computation complex enough to justify the use of such a machine would need to carry out several stages, which involved the operators of the machines inspecting their current state and mounting a different tape for the next step. The choice of tape would depend on the results so far obtained.

With a computer, unlike a tabulating machine, player piano, or electronic loom the distinction between program and data becomes meaningful. Some of the coded symbols read from the control tapes

[3] John von Neumann, "First Draft of a Report on the EDVAC," *IEEE Annals of the History of Computing* 15, no. 4 (October 1993):27-75.
[4] Thomas Haigh, "Introducing the Early Digital", in *Exploring the Early Digital*, ed. Thomas Haigh (Cham, Switzerland: Springer, 2019):1-18.

represented instruction codes, telling the machines to add, subtract, multiply, divide, copy numbers between registers, or in the case of the Mark 1 to perform more complex operations such as logarithmic or trigonometric functions. Other coded symbols represented the numbers on which these operations would be carried out. On a micro level, both kinds of reading controlled machinery. Even the symbols representing data were read by controlling a mechanism that replicated the numbers in a register so they would be available to be worked on. But considered from the viewpoint of the computer as a whole, the distinction between instructions and data was meaningful. Instructions were active; data passive.

Some scholars try to explain the invention of the computer as a conceptual breakthrough in the realm of logic, but in truth the idea that a mathematical engine could be controlled by coded instructions seems to me an incremental step for anyone who can conceive of an automatic calculating engine in the first place and is familiar with the technologies of digital reading used devices such as automatic looms. It was conceived independently by several inventors in different times and places, including Charles Babbage, Konrad Zuse, and Howard Aiken. The practical complexities in building an automatic calculating mechanism were considerable, and famously defeated Babbage, but the conceptual jump to the coded instruction seems to us a simple extension of earlier digital reading practices.

Automating Algorithmic Control

Algorithms are a central concept in computer science and, more recently, an object of fervent analysis within STS and media studies. An algorithm is, essentially, a step-by-step procedure to carry out a task – equivalent to a *method* in applied mathematics. Most useful algorithms require two capabilities, known informally as branching and looping or more formally as selection and repetition. Repetition means that some steps need to be repeated until a certain condition is satisfied. Selection means that the algorithm can follow one of several possible paths depending on a specified conditions. (Looping is in fact a special case of branching). For this book, we say that any programmable machine able to automate looping and branching is an example of *algorithmic control*.

Tape-controlled computers of the kind devised by Aiken and Zuse could execute programs, but because of their player piano style control systems these programs did not fully automate algorithmic control. They could be made to loop, by the simple expedient of gluing the ends of the control tape together to form an actual loop. In fact, that is where the phrase *looping* comes from. The Harvard Mark 1 could even halt the loop automatically once a specified condition had been met. But to branch they required their human operators to load the appropriate tape. Hence such machines had a degree of automatic control, but not algorithmic control. The execution of any reasonably complex algorithm would require a partnership between the machine and a human operator in which the machine carried out specific sequences of operations but periodically shut down until the human operator carried out the control operations needed to determine what happened next.

Charles Babbage's proposed, but never built, analytical engine would have had algorithmic control – its control cards would have been wired together to form a tape, similar to that in the tape-controlled computers of the 1940s, but unlike them it could wind its tape backwards or forwards under program control to repeat or skip instructions.

Because Babbage never managed to build, or even fully design, his analytical engine branching and looping operations were not in fact automated until ENIAC became operational in 1945. However ENIAC initially used a rather cumbersome one-of-a-kind control system, which unlike the tape controlled computers did not explicitly code program operations as a sequence of symbols. Whereas changing the program carried out by a tape-controlled computer took nothing more than loading a new tape with different instructions punched into it, changing the program executed by ENIAC involved setting up a new configuration of switch settings and patch wires across its many semi-autonomous panels.

Subsequent programmable electronic computers were patterned after the EDVAC, as described by von Neumann, which used a much simpler control system structured around a large electronic memory. The memory was broken into addressable chunks, which von Neumann called *minor cycles* though the computing community soon replaced this with *words*, a choice that revealingly emphasized the symbolic nature of the contents of memory and its kinship to text. EDVAC would read its programs digitally from paper tape and transcribe them into bit patterns coded as electronic pulses circulating at high speed within mercury delay lines. These memories would thus hold working data and program instructions, which could be accessed rapidly.

Each word of memory could hold either an instruction code and associated parameters or a chunk of data for the instructions to manipulate. A special memory location within the processor, soon to be known as the *program counter*, held the address of the instruction currently being executed. Whenever an instruction finished this automatically incremented, so that the next instruction came from the next memory address, but the scheme made branching and looping extremely easy to implement. To make the computer jump elsewhere in the program, just write an instruction to load a different number into the program counter. Such a computer could, within the limits of its memory size and the patience of its operators, execute algorithms of arbitrary complexity without human intervention. This basic control scheme has been used by computers ever since.

Mapping both instructions and data into a single space of memory addresses was central to the power of modern computers to execute complex algorithms. Because program instructions and data were held in the same grid of memory words, programmers could manipulate instruction codes using the same operations that worked on other data. For example, a program could overwrite itself with new code loaded from a paper tape. Referencing complex data structures becomes much easier than in systems controlled directly by instruction tapes.

The combination of an addressable memory with a program counter had a huge impact because it enabled the branching and looping affordances required to automate algorithmic control. As a conclusion, this may strike you as unsurprising or even predetermined. What we are calling *algorithmic control* here is functionally equivalent to the capability referred to by computer scientists as *Turing completeness* – essentially the ability to follow coded instructions that include a conditional branch. To treat the development of this capability as foundational to everything computers became from the 1940s onward is hardly novel. Yet to arrive here by a different path gives a different meaning to the claim. Theoretically inclined analysis, such as that offered by Martin Davis in *Engines of Logic*, tends to treat programmable computers as if their creation was inspired by the mathematical insights of Alan Turing and as if they were the product of a single conceptual leap.[5] Viewing this history from a media-centric viewpoint, grounded in a working through of the affordances of digital reading and the creation of new media and new techniques to better support it, makes the step of adding a branch capability to

[5] Martin Davis, *Engines of Logic: Mathematicians and the Origin of the Computer* (New York, NY: Norton, 2001)

the long-established practice of digital control seem, while still consequential, much less of a rupture with earlier technological and human practice.

We like to think, however, that reaching this conclusion by working upwards from the affordances of digital reading and stressing the practical difficulty of building a large, addressable, writable electronic memory sheds new light on the old story. My work with Mark Priestley in *ENIAC in Action* on the invention of the modern computer tells a story something like this: during the ENIAC project Presper Eckert invented delay line memory, a digitally readable and writable medium in which a lot of numbers could be stored. The medium came first, and everything in the First Draft was a thinking through of the possibilities opened up by this new medium for architectures of automatic control. The modern computer is what happened when Eckert's memory technology met von Neumann's need for a computer that could model the explosions of hydrogen bombs. Once a plausible mode of operation was identified for a large, addressable memory that could be read and written at electronic speeds it took at very little time for von Neumann to suggest storing both program instructions and working data within it. In the absence of such a technology it would have made sense to contemplate their comingling.[6]

Are Program Instructions Numeric

To continue with the distinction between numeric and symbolic senses of digitality raised in the first section of this book, we might ask whether the symbols held in computer memory to code instructions and textual data are digital because they are numbers or digital because they are symbols. In other words, what's digital about computer instructions? About computer data? Are their digitalities numeric or symbolic?

Some kinds of computer data have undeniable numerical significance, for example the numbers created by digitally sampling audio inputs. But one of the core features of the modern computer is that the same words (or bytes) of computer memory can be used to store other kinds of data and machine instructions. So the relevant question is: have text and instructions similarly been converted into numbers, or should we consider their representations within computer memory and storage media to be coded symbols but do not have numerical significance?

We previously quoted von Neumann's remark in the *First Draft of a Report on the EDVAC* as noting that a computer memory "requires perfectly distinct and independent registration and storage of digital or logical symbols." This tips us off to von Neumann's opinion on the issue. Because he used *digital* in the narrower, numerical sense he felt obliged to note that the memory could also store "logical symbols" – presumably those words of memory holding textual data or machine instructions.

Programmers became used to switching between different representations of the same bit pattern. People using the personal computers of the early-1980s were programming with very basic tools, and often directly manipulated the contents of specific memory locations. One might represent the eight bits that made up each byte either as a sequence of 0s and 1s, as two hexadecimal digits, as a three digit decimal number, or as whatever character or symbol the vendor's customized extension of the ASCII standard mapped to that particular bit pattern. Computer manuals often included an appendix listing these different representations in different columns.

[6] Thomas Haigh, Mark Priestley, and Crispin Rope, *ENIAC In Action: Making and Remaking the Modern Computer* (Cambridge, MA: MIT Press, 2016), ch. 6.

To make this more tangible for those who have not programmed in machine language, consider a simple, 8-bit microprocessor such as the Z80 used in many home computers of the early 1980s. Its instructions and data were both represented as patterns of data bytes. For example, the bit pattern 1001100 could be interpreted in several ways. As specified by the ASCII standard baked into several parts of the machine's hardware, when generated by a keyboard controller, output to a printer, or fed to a character display circuit it coded the letter v. When executed as an instruction, though, the same big pattern coded the HALT operation, bringing the machine to a stop until an interrupt signal was received. When interpreted as a number, for example when loaded into the accumulator for use by an ADD instruction, it corresponded to 118 in decimal. Programmers working closely with the machine would have been more used to seeing it displayed as 76 rather than 118, using the compact hexadecimal notation in which each byte was represented with just two digits (represented using the symbols 0 though F – employing A, B, C, D, E, and F as digits rather than letters).

In other words, because programmable digital computers can interpret input codes as instructions or as data they have always been digital in the symbol processing sense rather than digital in the numerical sense. This becomes inescapable as soon as they begin to process text and graphics as well as numbers. [7] There's no reason to privilege the numerical interpretation of 1001100 as 118 or 76 over the interpretation of the same bit pattern as HALT or v – all three readings were embedded in different parts of the hardware of the same computer. We conclude that computer programs and many kinds of computer data are digital in the symbolic sense of digital media and digital communication, but not in the more literal sense of having been converted into actual digits.

Algorithmic Interchange Between Digital Representations

The distinctive affordances of digital reading and writing described here, including automatic transcription between interchangeable representations and algorithmic control, underpin some of the other distinctive affordances of modern computers. In part 1 of this book we identified the interchangeability of different media from which the same sequences of encoded symbols could be read as a key digital affordance. When coupled with automated processes of digital reading and writing, this permits the transcription of symbol sequences from one medium to another, something that takes place constantly and invisibly within computer systems to create the illusion of digital immateriality.

---

[7] This distinction is rather subtle. From the beginning it has been possible to use digits to code other kinds of symbols, or to code logical values. Even ENIAC, for example, used numbers to stand for Boolean or categorical variables. In the Monte Carlo simulations it ran in 1948, each neutron flying through the core of an exploding nuclear bomb was represented using the 80 decimal digits available on a single punched card. Columns 1 to 7 represented the time interval as a seven digit number. Columns 51-55 represented the velocity of the neutron, as a four digit decimal number. And so on: most of the digits on the cards represented digital approximations of physical quantities. Column 11, however, represented event type: 3 for absorption, 4 for total escape, 5 for fission, or 6 for census. ENIAC's hardware interpreted this as a decimal digit, but the program logic treated it as a categorical variable with four valid values. The difference is that in later computers there are plenty of cases where computer hardware explicitly treats bit patterns in non-numerical ways, using circuits that are incapable of extracting numerical meanings from them.

Having now explored the algorithmic control central to modern digital computers we can return to this topic. Many of the operations needed to reliably transcribe symbols from one medium to another, including error detection and correction operations, was left to dedicated circuits in different parts of the computer and its peripheral units. Some computers, including many of IBM's early 700 series mainframes, even had separate peripheral controllers, essentially small computers, to control their tape drives. Devices such as CD players use specialized chips to decode digital symbols read from disk.

To give another example, I have in my laboratory an ASR-33 Teleype. These devices were the main way in which users accessed online computer systems from the mid-1960s to the early-1970s. Video terminals were rare and expensive during this period. The teletype was essentially an electric typewriters that transmitted keypunches to a remote computer and typed out its response. It was thus created specifically to read and write digitally: encoding key presses as ASCII characters for transmission to a computer and listening for signals combing back the other way, which it rendered as printed characters. Its entire reason for being was to convert between different digital representations of the same symbols. Yet the device itself contains almost no electronics. The key presses are converted into ASCII codes by a system of mechanical code bars running beneath the keys, not by digital electronics. The tape punch and tape reader mounted to the side of the keyboard provides another mode of operation, in which the symbols relayed to the computer come not from key pushes but from a paper tape. In that case, the tape reader communicates the presence and absence of holes across its eight tracks via the movements of a set of eight mechanical levers, which activate the same system ordinarily controlled by the keys.

It is, however, well known feature of electronic computers that any process achievable with software can be reimplemented with special purpose hardware, or vice versa. Modern keyboards are themselves simple computers that use programs to look up the codes to be produced each time a key is pressed. Software has replaced hardware. More generally, code can simulate the operation of non-existent hardware. As a technique this goes back to the 1950s and the development of systems such as Speedcoder for the IBM 701though the vocabulary used to describe it, the *virtual machine*, is a newer coinage.[8]

Any job that can be done by a general purpose computer running particular software can also be accomplished by special purpose hardware. One of the things that the algorithms implemented as programs for these computers could do is to automatically carry out processes of digital reading and writing, for example transcribing digital symbols from one medium to another. To give another example, the CD players of the 1980s relied on special purpose chips to decode the highly redundant stream of bits read from the disk and convert it into a stream of audio. Early CD-ROM computer drives retained an analog audio output, to be cabled into an audio input on the computers' sound card so that audio CDs could be played and games could pipe audio tracks from the disk to the speakers or headphone of the computer system. By the late-1990s, however, computers had more than enough power in their main processors to decode audio data in software, extracting the audio data directly from the disk and algorithmically processing it into music.

[8] Thomas Haigh and Paul E Ceruzzi, *A New History of Modern Computing* (Cambridge, MA: MIT Press, 2021), 368-370.

For practical purposes, then, the question of whether to implement any particular function in hardware or in software is a matter of convenience, efficiency, flexibility, and economic viability. The unmistakable trend of the last fifty years has been towards general purpose hardware coupled with code rather than special-purpose digital technology. Today almost every consumer device holds an embedded microcontroller, customized to its specific job with code loaded into a persistent memory. Field programmable gate arrays customize their internal hardware based on logical specifications which are themselves the output of computer programs. In a sense, is an extension of the approach taken by Claude Shannon in demonstrating the interchangeability of logical propositions and switching circuits.

Modularity and Layering

The interchangeability of hardware and software underlies our key concerns in the second part of this book. As Jean-Francois Blanchette noted in "A Material History of Bits," of the most important features of digital computers, and central concepts in computer science, is the idea of stacking layers of abstraction on top of each other.[9] Hardware and software technologies are often conceptualized as a hierarchical stack, with the inner workings of different levels of the stack being hidden from each other. The virtual machine controlled by code at one level in the stack is not a piece of hardware but a layer of code which itself runs not on real hardware but on another virtual machine. In this sense the concepts of virtuality, modularity, interoperability, and stacking of abstractions are deeply intertwined.

This concept appears in different forms, for example in the famous OSI seven layer model for networking, or in the widespread practice of running code on virtual machines rather than directly on hardware. The feasibility of this approach is a consequence of the flexibility provided by algorithmic control. Programs write and rewrite digital symbols, for example to translate code for a virtual machine into code for a physical machine, or to turn a request to transmit a network packet into a sequence of operations for an ethernet controller. Database management systems shield users and applications from the actual storage locations and formats of data files; memory management hardware maps virtual address spaces onto real memory. As Paul Dourish has suggested

> one needs to push down from an application, a service, or a user experience into the bits, bytes, protocols, packages and data structures that enliven it…. As one pushes from the high level to the low, one has to be able to develop an understanding of the interlocking of these various components. One has to undo the separation between different 'layers' and 'levels' that computer scientists refer to as 'the stack' and recognize that the actual encounter with technology is not a serial encounter with each layer but a simultaneous encounter with a slice through the whole…[10]

The same facilities also underpin another crucial feature of today's computer technologies: modularity and interoperability. If standard interfaces are defined between the layers then one piece of hardware or software can be swapped out for another. Old programs work on a new operating system because they interact with it using a standard API. Google Chrome works the same way over a cellular

[9] Jean-François Blanchette, "A Material History of Bits," *Journal of the American Society for Information Science and Technology* 62, no. 6 (2011):1042-1057.
[10] Paul Dourish, *The Stuff of Bits: An Essay on the Materiality of Information* (Cambridge, MA: MIT Press, 2017), 206.

connection, Wi-Fi connection, or ethernet connection because the details of the network connection it is running over is hidden from it by the operating system.

The stacking of platforms accounts for the difficulties we face in trying to analyze computer applications using the same tools that historians of technology and science studies scholars have applied to other technologies. For example, Donald Mackenzie famously supported his call to "open the black box" of technology by tying specific details inside nuclear missile guidance systems to strategic shifts in American nuclear doctrines.[11] Such arguments are harder to mount across the stack of technologies found in modern computer systems. When studying social interaction on Facebook the specific of the firm's algorithms are unmistakably relevant, but there is only a lose coupling between underlying network technologies, web protocols, or processor instruction sets and the kinds of behavior that occur in the online communities that these technologies make possible. Any attempt to mimic Mackenzie's work by explaining the functioning of Twitter with reference to details of the Intel instruction set would be less than convincing.

Yet we should not therefore assume that the digitality of "the digital" is found only in the lower levels of these stacks of platforms, with the processors and memory chips, and that understanding what is happening down there is only indirectly useful in understanding the kinds of affordances that shape user behaviors and experiences. In fact the very existence of an automated stack of platforms is a hallmark of the combination of digital media and automated digital control that has defined modern computing since the 1940s. Thinking this through offers a historical route to understand what is truly digital about these phenomena.

Digital Networks

We already mentioned the centrality of the idea of a stack of loosely coupled protocols to modern approaches to computer networking. This stacking is, by the argument sketched above, fundamentally digital.

In the second part of the this book we will also be exploring other aspects of the digitality of modern, packet switched, computer networks such as the Internet. Shannon's model of communication was fundamentally about synchronous, point-to-point communication in which encoded symbols flow from a sender to a received. Packet switched networks such as the ARPANET, the precursor to the Internet, are composed of connections of this kind, known as links. Each link relays coded symbols between two points. But to pass from its ultimate sender to its eventual receiver each message is broken up into small data packets which are routed separately from link to link over the network to arrive at their eventual destination. Shannon's model corresponds to the lowest levels in this hierarchy of abstractions, known in the OSI formulation as the physical layer and the link layer.

Modern network communication is not, then, an alternative to Shannon's conceptualization of digital communication but rather a set of additional levels of complexity and functionality erected on top of it to manage the topology of networks composed of many links functioning across different media. Networks assign metadata and addresses to each data packet, and wrap packets up inside other packets

[11] Donald MacKenzie, *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance* (Cambridge, MA: MIT Press, 1990).

in complex processes of digital reading and rewriting. As inside a digital computer, data symbols are constantly being transcribed and repackaged from one representation system to another.

This approach was made practical only by the affordances of algorithmic control. In the original ARPANET, for example, each link was made between two IMP systems and each IMP was a fully-fledged computer running specialized software to manage the connection and route packets over the network. Today, your home internet router is likewise a powerful computer running specialized software to handle the complicated job of controlling network traffic and transcribing data between packets on your internal networks and packets on the Internet itself.

Conclusions

Digital control automates sequences of operations. Like other forms of automation, this has profound effects on the organization of the work being automated, the task as experienced by humans working with the machine, and the skills they need. The question is whether there are any fundamental characteristics of digital technologies that create meaningful parallels between all these local transformations, or at least common analytical tools with which to understand the range of digital practices and cultures that develop though them. Our challenge is to develop insights of the kind I have gestured to here, about the characteristics of digital representations and the capabilities of digital control, sufficiently to provide a basis for understanding what is truly "digital" about different digital practices and cultures and what is merely contingent and local.

Machines read by using sensors to control part of their internal state. In that sense, all digital reading is a form of control. But since the 1940s, automatic computers have distinguished between instructions and data. This allows for sequences of symbols to control the operation of the machine in more complex ways, interacting with data inputs to determine patterns of branching and looping through programs. We call this algorithmic control.

From the viewpoint of computer science, the only thing that computers do is to transform sequences of encoded symbols. Conceptually hardware and software are interchangeable – any algorithm can be accomplished using a special purpose machine or by writing coded instructions for a general-purpose processor. Pragmatically, though, most tasks are accomplished using simple general-purpose hardware coupled with coded instructions. Hardware and software are typically conceptualized as many-layered stacks defined by APIs and virtual machines, which hide their internal configurations from each other by allowing only tightly regulated exchanges of symbols between them.

That brings us to the questions to be explored in the second section of this book. Why are modularity, virtuality, and the stacking of abstractions so important to digital platforms? What do they have to do with the core digital affordances we have so far considered? What, really, is digital about modularity? About virtuality? About digital data, universal access, or digital objects?

Agar, Jon. *The Government Machine: A Revolutionary History of the Computer*. Cambridge, MA: MIT Press, 2003.

Blanchette, Jean-François. "A Material History of Bits." *Journal of the American Society for Information Science and Technology* 62, no. 6 2011): 1042-1057.

Davis, Martin. *Engines of Logic: Mathematicians and the Origin of the Computer*. New York, NY: Norton, 2001.

Dourish, Paul. *The Stuff of Bits: An Essay on the Materiality of Information*. Cambridge, MA: MIT Press, 2017.

Haigh, Thomas. "Introducing the Early Digital." In *Exploring the Early Digital*, edited by Thomas Haigh, 1-18. Cham, Switzerland: Springer, 2019.

Haigh, Thomas, and Paul E Ceruzzi. *A New History of Modern Computing*. Cambridge, MA: MIT Press, 2021.

Haigh, Thomas, Mark Priestley, and Crispin Rope. *ENIAC In Action: Making and Remaking the Modern Computer*. Cambridge, MA: MIT Press, 2016.

MacKenzie, Donald. *Inventing Accuracy: A Historical Sociology of Nuclear Missile Guidance*. Cambridge, MA: MIT Press, 1990.

Priestley, Mark, and Thomas Haigh. "The Media of Programming." In *Exploring the Early Digital*, edited by Thomas Haigh, 135-158. Cham, Switzerland: Springer, 2019.

von Neumann, John. "First Draft of a Report on the EDVAC." *IEEE Annals of the History of Computing* 15, no. 4 (October 1993): 27-75.

3.1: What's Digital About Nicholas Negroponte?

In the first two parts of this book we developed a rigorous analytical description of digitality and its affordances grounded in the sense of digitality developed in the 1940s by pioneers of digital computing and communications. This reinterpreted aspects of the history of computing around practices of digital encoding, in ways that de-exceptionalize algorithmic control and emphasize continuities between computing and other media practices.

In this final section, we turn back to the career of digitality as a concept to explore its recent, sometimes perplexing, evolution. In the 21st century, I believe, discussion of things like *the digital*, *the digital universe*, *digital humanities* and the like has incrementally revised widespread understandings of digitality to the extent that much current discourse flatly contradicts the original definition of digital and analog proposed in the 1940s. In contrast, dominant discourse into the 1980s and 1990s, whether in the engineering traditions that led to the introduction of CDs, DVDs and ISDN communications or in the analysis of theorists like Nelson Goodman, was generally compatible with what we might, in the spirit of that era's musical heritage, call the OD or Original Digital.

Digitality has become a concept overloaded with a confusing variety of incompatible meanings. In many academic formulations, such as digital humanities, digital methods, and digital cultures it often signifies little more than a connection to computer technologies and to the Internet. Young people, who as always are assumed to have mentally adapted to new technology, are called *digital natives* in the popular press. In the entertainment industry, as evidenced by the digital edition of the Playstation 5, it refers to the distribution of data in forms invisible to the naked eye. In this discourse, invisible media are digital while anything you can touch, even an optical data disk, is not digital. SAP, the software company around whose products most large companies long ago rebuilt themselves, has sold the idea of migrating to cloud-based versions of its products as a *digital transformation*.

Discussion of *the digital* or *the digital universe* has recently become the dominant hand-waving description of our computer-mediated present, replacing earlier formulations such as *the information society* or predictions for the impending convergence of computing and communications. Even historical accounts have begun to replace "computers" and "information" with "digital." George Dyson somewhat confusingly called his book about John von Neumann's computer project *Turing's Cathedral: The Origins of the Digital Universe*.[1] The more sober academic historian David Gugerli followed suit with *How the World Got Into the Computer: The Emergence of Digital Reality.* Gugerli consistently juxtaposes the *digital space* and *digital reality* inside computer systems with the analog versions to be found elsewhere.[2]

---

[1] George Dyson, *Turing's Cathedral: The Origins of the Digital Universe* (New York: Pantheon Books, 2012).
[2] David Gugerli, *How the World Got into the Computer: The Emergence of Digital Reality* (Zurich, Switzerland: Chronos Verlag, 2022). See pages 91 and 110-111.

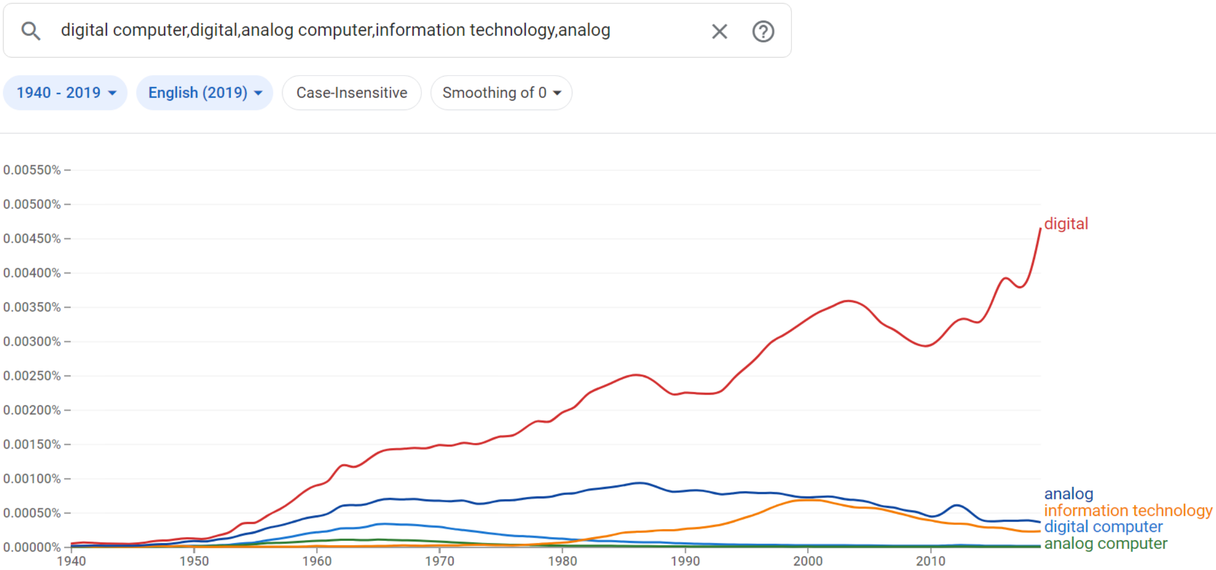
While Gugerli used the term *digital space* largely to describe the world of data inside computers, on occasion he spoke of programmers as “inhabitants of digital space” or of computerizing offices relocating to digital space. Neither author found it necessary to define digitality or make explicit its connection to computer technology.

To tell the story of digitality’s evolution within the discourse of different communities is to treat it as an actors’ category, charting the various meanings given to it by others. Like almost everything else to do with computer technology the digital discourse tells a story about the future. Specifically a ruptured future, in which technology has made the past irrelevant. Over time digital moved from a description of a class of computer, to a description of an approach to electronic circuit design, to a description of certain media formats, to a description of anything related to computers and the Internet, and finally to a designation for technologies that give the illusion of immateriality. For example, the “digital edition” games console is defined by what it lacks: an optical disk drive able to read data from DVDs. In this context, anything visible is assumed to be analog. Yet the D in DVD stands for digital: the disk is, from an engineering viewpoint, no less digital than the download. Likewise, those of my colleagues who call themselves “digital historians” remain unmistakably corporeal. Nothing could signal more clearly that we have reached a point at which, in a process of radial evolution, different sense of digitality have become specialized to the extent that they are flatly incompatible with each other and with the OD of the 1940s.

This proliferation of meanings must be understood as a historical process: we cannot arbitrarily proclaim some of them as deviations from the “true” meaning of digitality and others faithful to this glorious tradition. Yet by exploring the implied definitions of *digital* used to structure fields such as *digital heritage*, *digital cultures*, and *the digital humanities* we can begin to understand their relationship to the OD world of engineering and to the cultural discourse of the 1990s.

This introductory chapter for section 3 is called “What’s Digital About Nicholas Negroponte” to highlight the role of Negroponte’s 1995 book *Being Digital*, and the earlier *Wired* magazine columns on which it was based, in establishing the 21st century discourse of digitality. Negroponte did more than anyone to spread the fallacy that digitality is inherently immaterial.

The Uniquity of Digital Discourse



This chart, from Google's Ngram Viewer, shows the relative frequency of several relevant terms. Prior to 1940s *digital* and *analog* were rarely used. While this tool is far from perfect, its very large corpus makes it useful to get a general sense of change over time in the use of particular phrases. From the mid-1940s to the mid-1960s use of *digital* and *digital computer* both rose, as did use of *analog* and *analog computer*. Throughout the 1950s and 1960s analog and digital computers coexisted. The titles of textbooks and university classes would include the word "analog" or "digital" as appropriate to avoid confusion. Eventually the increasing power and reliability of digital computers and their falling cost squeezed analog computers out of the niches, such as paint mixing, in which they had previously been preferred. Most analog computer suppliers left the industry, although Hewlett Packard made a strikingly successful transition to the digital world. By the 1970s it was generally no longer necessary to prefix computer with "digital" and consequently the word was less frequently encountered in computing circles.

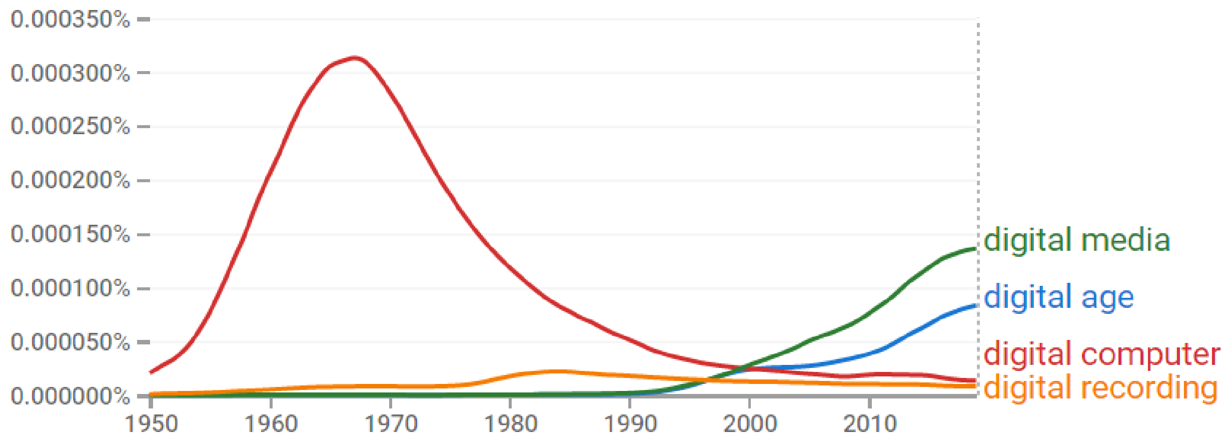
As a result, the qualifier *digital* was increasingly likely to be dropped as the 1970s wore on, leaving just *computer*. For those who wanted a fancier name, the term *information technology* began to rise just as *digital computer* fell out of fashion.

The terms analog and digital retained their relevance in other areas, particularly for electronic engineers, telecommunications engineers, and media specialists. Even digital computers include analog circuits. For example, disk drives, sound cards, and modems all include analog electronics for input and output as well as digital interfaces to the rest of the computer system. Use of the word *digital*, however, continued to rise through the 1970s and into the mid-1980s, propelled by enthusiasm for digital communication and media technologies such as the wildly popular compact disk.

The chart shows a brief drop in occurrences of *digital* in the late-1980s, followed by a plateau until around 1992 when occurrence began to rise again. The drop was probably a consequence of the increasing familiarity of digital media. For example, early CDs even featured a labelling scheme of AAD, ADD, and DDD to let purchasers know whether their recording and mixing had also been accomplished digitally. The standard logo placed on each player read "Compact Disk Digital Audio," further foregrounding the digitality of the new format. Faced with this, an audio enthusiast whether to purchase a CD player in 1985 might want to read about the unfamiliar characteristics of digital recoding. A few years later when CD sales had eclipsed those of vinyl records the discourse had become more specific to the virtues of the particular player or recording.

Being Digital

So why, then, did occurrence of the word *digital* spike again in the mid-1990s to reach new highs around the millennium? The answer certainly has something to do with the sudden commercialization of the Internet and the rapid adoption of the Web, but why were these things increasingly associated with the rhetoric of digitality? I argue that *digital* acquired a new resonance from 1993, with the launch of the instantly fashionable *Wired* magazine. The magazine's title evoked both electronic circuits and drug heightened fervor. In first editorial proclaimed that the "the Digital Revolution is whipping through our lives like a Bengali typhoon," just as enthusiasm was building for the information superhighway and the Internet was being opened to commercial use. Wired published lists of the "Digerati" – a short lived coinage used to justify something akin to People's list of the sexiest people alive as judged on intellectual appeal to libertarian techno geeks.



3

3 https://books.google.com/ngrams/graph?content=digital+age%2Cdigital+computer%2Cdigital+media%2C+digital+recording&year_start=1950&year_end=2019&corpus=26&smoothing=3&direct_url=t1%3B%2Cdigital%20age%3B%2Cc0%3B.t1%3B%2Cdigital%20computer%3B%2Cc0%3B.t1%3B%2Cdigital%20media%3B%2Cc0%3B.t1%3B%2Cdi

The new wave of discussion of digitality was driven not by discussion of digital computers, or the specific techniques of digital recording, reference to which continued to decline, but by new formulations of the kind advanced by *Wired* such as *digital media* and vaguer invocations such as the newly popular *digital age*.

As Fred Turner showed in his book *From Counter Culture to Cyberculture*, Wired magazine was one in a series of bold projects created by a shifting group of collaborators orbiting around libertarian visionary Steward Brand.[4] Brand had created the Whole Earth Catalog back in the 1960s and a pioneering online community known as the WELL (Whole Earth 'Lectronic Link) in the 1980s. His circle saw technology as a potentially revolutionary force for personal empowerment and social transformation. In the early 1990s this held together an unlikely alliance, from Newt Gingrich who as House Speaker suggested giving laptops to the poor rather than welfare payments, to the futurist Alvin Toffler, conservative activist and prophet of unlimited bandwidth George Gilder, vice president Al Gore who championed government support for high speed networking, and Grateful Dead lyricist Lou Perry Barlow who had founded the Electronic Frontier Freedom to make sure that the new territory of "cyberspace" was not burdened by government interference.

One of the magazine's key figures, Nicholas Negroponte, was particularly important in promoting the idea of "the digital." Negroponte was the entrepreneurial founder and head of MIT's Media Lab, a prominent figure in the world of technology whose fame owed much to a book written by Brand. Negroponte took "digital" far beyond its literal meaning to make it, as the title of his 1995 book *Being Digital*, suggested, the defining characteristic of a new way of life. His project was to elevate digitality to describe new era in human history. As he explained: "Computing is not about computers anymore. It is about living." He heralded "digital life-styles" and called digitality a "radically new culture." To Negroponte it wasn't our media that was about to be digital, it was ourselves. (p.6) And discourse is, I suggest, the vector by which a new sense of digitality spread that was subsequently embedded in constructions such as *digital cultures*, *digital humanities*, or *the digital universe*.

As traditional for a book touting the transformative potential of IT, *Being Digital* made its case by predicting the further rather than exploring the present. Here is a taste:

> Early in the next millennium, your left and right cuff links or earrings may communicate with each other by low-orbiting satellites and have more computer power than your present PC. Your telephone won't ring indiscriminately; it will receive, sort and perhaps respond to your calls like a well-trained English butler. Mass media will be refined by systems for transmitting and receiving personalized information and entertainment. Schools will change to become more like museums and playgrounds for children to

---

gital%20recording%3B%2Cc0#t1%3B%2Cdigital%20age%3B%2Cc0%3B.t1%3B%2Cdigital%20computer%3B%2Cc0%3B.t1%3B%2Cdigital%20media%3B%2Cc0%3B.t1%3B%2Cdigital%20recording%3B%2Cc0

[4] Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago: University of Chicago Press, 2006).

> assemble ideas and socialize with children all over the world. The digital planet will look and feel like the head of a pin.
>
> As we interconnect ourselves, many of the values of a nation state will give way to those of both larger and smaller communities. We will socialize in digital neighborhoods in which physical space will be irrelevant and time will play a different role. Twenty years from now, when you look out of a window what you see may be five thousand miles and six time zones away…

Like any expert set of predictions this cluster of promises extrapolated social and technology change to yield a mix of the fancifully bold, the spot on, and the overly conservative. Our phones do support call screening, although voice calls have become so rare than any unexpected call from an unknown number is probably spam. Online communities have contributed to increased cultural and political polarization. Netflix, Twitter, blogs and YouTube have done rather more than "refine" mass media.

As for those satellite cufflinks, well the "internet of things" remains a futuristic vision more than a daily reality. However when the cufflinks of the future do feel the need to communication they seem more likely to chat over local mesh networks than precious satellite bandwidth. This prediction was perhaps an example of the role of future visions in promoting the interests of the visionary. Negroponte was then on the board of Motorola, which poured billions into the Iridium network of low earth orbit satellites for phone and pager communication. That business collapsed within months of launch in 1998 and plans to burn up the satellites to avoid leaving space junk were cancelled only after the defense department stepped in to fund their continued operation.

Strip away the specifics of the predictions and the commercial interests they served, and Negroponte's central claim was that in the past things "made of atoms" had been all-important. In the future everything that mattered would be "made of bits." Looking ahead a few years, this time more accurately, he promised that "The methodical movement of recorded music as pieces of plastic, like the slow human handling of most information in the form of books, magazines, newspapers, and videocassettes, is about to become the instantaneous and inexpensive transfer of electronic data that move at the speed of light. In this form, the information can become universally accessible… The change from atoms to bits is irrevocable and unstoppable." (p. 4)

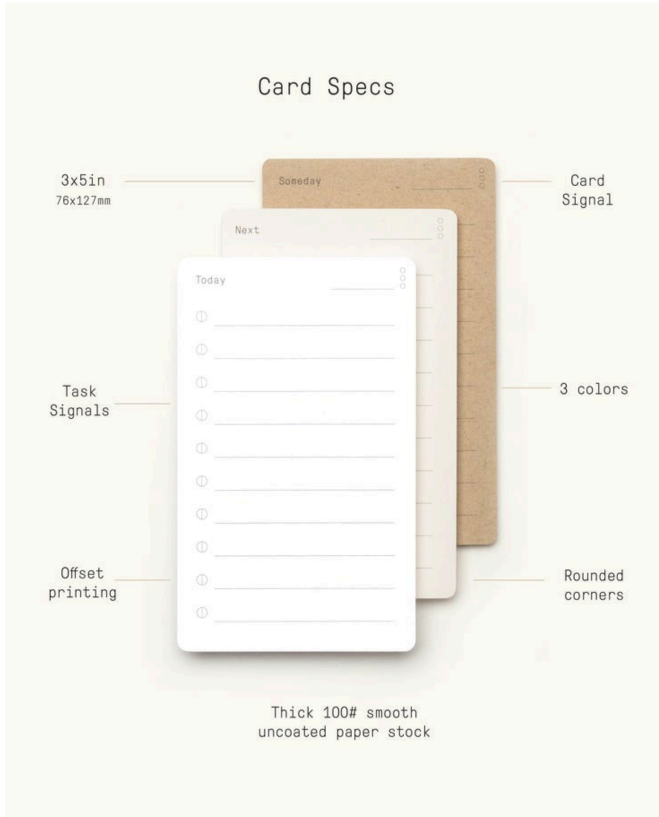
Negroponte wasn't wrong. Napster and MP3s were about to upend the business model of the music industry, just as Netflix would eventually bury Blockbuster, just as most of the newspaper and magazine industry would die slowly and painfully. But notice what else was going on. Negroponte was not only touting the future of digital media and the convergence of media and computing industries, something widely predicted since the 1970s. He was also explicitly equating digitality with electronic transmission of bits, rather than the physical movement of disks or tapes. Bits were no longer read by examining the content of matter (i.e. atoms) but floated altogether free of physical constraints.

The focus on digital machine-readable representation made some sense: the computer is an exceptionally flexible technology whose applications gradually expanded from scientific calculation to business administration and industrial control to communication to personal entertainment as their speed has risen and their cost fallen. Each new application meant representing a new aspect of the world in machine readable form. Likewise the workability of modern computers depended on advances in digital electronics and conceptual developments in coding techniques and information theory. Negroponte's media-centric view of the future of computing was thus, in a way, an important corrective to popular accounts of the computer that focus on its abstract computational capabilities rather than its ability to communication.

Yet by reframing the juxtaposition as bits vs. atoms rather than digital vs. analog, Negroponte did more than anyone else to create a conceptual fissure between sense of digital and analog based on specific methods of encoding and reading information and those based on assumptions of materiality and immateriality. As Jonathan Sterne has noted, the idea of *the analog* has increasingly been romanticized as somehow more human and closer to nature than digitality. The real world, it is often suggested, is inherently analog. This is wrong, says Sterne. I agree: the world itself is neither digital nor analog, concepts that apply onto to the ways in which one thing represent another. Yet the understanding of *analog* as *not-digital* has led to absurdly broad definitions of *analog*. As Sterne put it, "If *analog* refers both the things that come into contact with digital technology—probably to be transduced by it—*and* to things outside the domain of digital technology that *do not* come into contact with it, the term expands to cover the whole of reality."[5]

Today the assumed immateriality of the digital combined with the long-established status of analog as the opposite of digital to yield the assumption that obviously material, or at least anything intended to be read by humans rather than machines, must necessarily be analog. For example, some people have rejected computerized task tracking systems, in favor of a simple but expensive system of Analog brand paper cards. Users write their tasks onto cards and shade symbols to represent their current status. This mirrors the sense of analog as meaning "not virtual" used by journalist David Sax in his high profile 2016 book *The Revenge of Analog: Real Things and Why They Matter.* His entertaining book was a mishmash of chapters about things are meaningfully analog, such as vinyl records and film, and chapters that things that are not such as paper, board games, and print.[6]

[5] Jonathan Sterne, "Analog", in *Digital Keywords: A Vocabulary of Information Society & Culture*, ed. Benjamin Peters (Princeton, NJ: Princeton University Press, 2016):31-44. Quote from page 38.
[6] David Sax, *The Revenge of Analog: Real Things and Why They Matter* (New York: Public Affairs, 2016).



Despite the widespread assumption that paper media are analog, there is nothing inherently analog about these "Analog Cards" sold by Ugmonk as an alternative to computer-based personal organizers. For example, when used as directed the task indicators are either fully filled in, half filled in, or empty to code three possible states.

New Digital Formulations

According to science fiction writer William Gibson "The future is already here – it's just not very evenly distributed."[7] Negroponte surely agreed: he was writing at a time when the capabilities of digital media had become clear based on lab and prototype applications but had not yet begun to seriously challenge most established business models. His vision for the near future was a working through of the consequences of more even distribution. Back in 1997, in his last column for Wired, he noted that "digital" was destined for banality and ubiquity as "Its literal form, the technology, is already beginning to be taken for granted, and its connotation will become tomorrow's commercial and cultural compost for new ideas. Like air and drinking water, being digital will be noticed only by its absence, not its presence."[8]

With those words, Negroponte declared success, bailed on the rhetoric of digitality, and headed off in search of the next big: the One Laptop Per Child project, a much-hyped effort to bring the

---

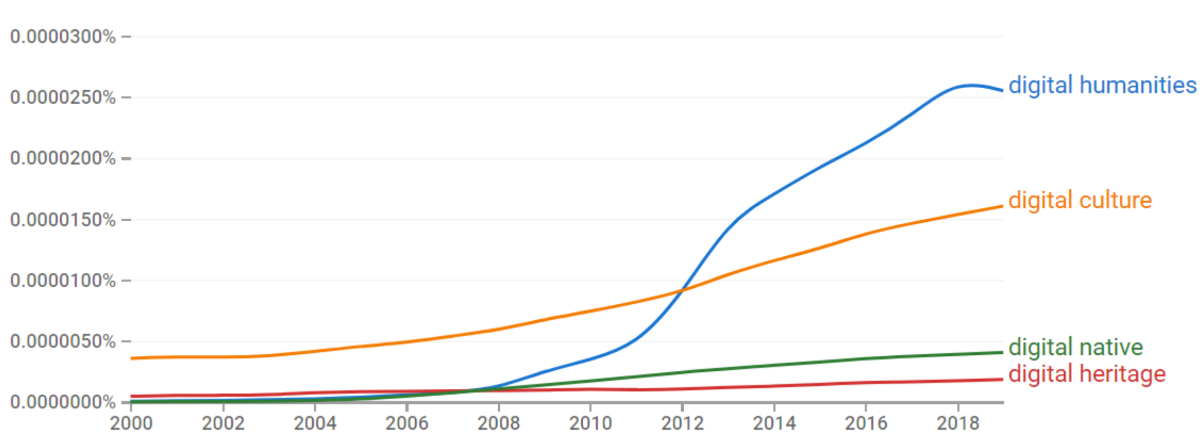
[7] The sentiment is Gibson's, although there is no record of him using those specific words until after they had become an aphorism. See http://quoteinvestigator.com/2012/01/24/future-has-arrived/.
[8] Nicholas Negroponte, "Beyond Digital," *Wired* 6, no. 12 (December 1998).

benefits of tinkering with computers to children in the developing world. As chronicled by Morgan Ames in her book *The Charisma Machine*, this debacle serves as an instructional tale in the folly of expecting normal people to think and act in accord with the precepts of MIT's celebrated hacker culture.

One might expect that, as Negroponte forecast, discussion of digitality begin to decline digitality as it entered the realm of the taken for granted. Even after once-unfamiliar technologies dissolve into our daily experience rupture talk and metaphors of revolution can continue to lurk in odd and unpredictable places. While we no longer think of the Internet as a place called *cyberspace* the military-industrial complex seems to have settled on *cyber warfare* as the appropriate name for online sabotage. The ghastly practice of prefixing things with an "e" has faded in most realms, but *e-commerce* is hanging on. Library schools with hopes of continued relevance my own institution dubbed themselves *iSchools*, copying the names of Apple's successful consumer products. There doesn't seem to be any particular logic behind this set of prefixes: we might all just as well have settled on *iWarfare*, cybercommerce and *e-school*. But these terms will live on, vestiges of the crisp future vision that destroyed itself by messily and incompletely coming true.

Digital has so far followed a different trajectory. The Google N-Gram chart shows a peak around 2002, shortly after the dot com crash ended the initial wave of Internet enthusiasm and utopian hype. In the years that followed, Web technologies and Internet platforms were woven ever more closely into our daily lives, to be taken for granted rather than reflected upon with awe.

Yet the 2010s were marked by a third and higher peak in discussion of *digital*. In part this reflected the replacement of formerly popular information-based phrases such as *the information age,* the *chief information officer*, or *the information society* with new names for similar things premised on digitality, such as *the digital*, *digital transformation* or *the digital universe.* The transition was particularly apparent in the worlds of academic and culture.



What many of these new concepts of digitality have in common is that they implicitly follow Negroponte in seeing digitality as the basis of new identities and work practices rather than simply new phenomena to study using conventional methods. A digital medium is specific and constrained; a digital culture, in contrast, permeates lives and societies; a digital native is an entire person; the digital age is putatively a new era in human civilization.

Humanizing the Digital

I will close this chapter with a few illustrative words about the digital humanities, as an example of one of the new fields defined with reference to digitality. The digital humanities movement was a push to apply the tools and methods of computing to the subject matter of the humanities. It functioned as a *computerization movement* of the kind described decades ago by Rob Kling and Susan Iacono.[9] Its adherents preached the potential of computerized tools, ran boot camps to spread their use, and sometimes argued that the invention of new technologies would dictate the adoption of new modes of scholarly research.

But what makes the digital humanities *digital*? Matthew Kirschenbaum led off the first chapter of the original 2012 iteration of *Debates in the Digital Humanities*, a volume intended to showcase intellectual diverse perspectives on the composition and mission of digital humanities, with a question: “What is (or are) the ‘digital humanities’ (DH), also known as ‘humanities computing?” Kirschenbaum suggested that the term “digital humanities” was first devised at the University of Virginia back in 2001 as the name for a potential graduate degree program. Those who came up with it wanted something more exciting than “humanities computing” and broader than “digital media,” two established alternatives. The new coinage spread widely through the *Blackwell Companion to the Digital Humanities* issued in 2004.[10]

Scholars identifying as digital humanists were preoccupied with definitional questions, a debate surely enflamed by the perception that for once there were actual resources at stake. Within a few years, a small group of well-funded institutions were building impressive new labs and research centers around digital humanities, a sharp contrast with the generally bleak prospects for employment and grant funding in the humanities. “Digital” scholars shot to the top of lists of hiring priorities across the academic world. One extreme example: in 2011 my own professional home, the history department at the University of Wisconsin—Milwaukee, employed 35 tenured or tenure track faculty members. Eleven years later, 21 of those faculty members have retired or moved on to jobs in better funded institutions. In a spectacular feat of downsizing, only one tenure track search was authorized by the university administration to replace those 21 lost colleagues: the recruitment of a “digital historian” who has, alas, himself already moved on to lusher pastures.

Historians are traditionally defined with a matrix of time, place, and intellectual approach. For example a cultural historian of nineteenth century Germany, or a social historian of colonial north America. Yet to identify as a *digital historian* or a *digital humanist* is to follow Negroponte

[9] Rob Kling and S Iacono, "The Mobilization of Support for Computerization: The Role of Computerization Movements," *Social Problems* 35, no. 3 (June 1988):226-343.

[10] Kirschenbaum Debates 2012.

in defining something of oneself as intertwined with digital tools, just like the other new concepts of *digital native* or *digital culture* which presuppose that immersion in these technologies has created new modes of thought and of social organization. To adopt these categories is both to accept the idea of a new world order and to situate oneself within it. On an operational basis, it is not clear to me exactly what makes a humanist digital. My sense is that the boundary shifts over time, as one would have to be using computers to do something that most of one's colleagues did not know how to do. Using email or a word processing program would not qualify, and having a home page or a Twitter account will no longer cut it. Creating an interactive computer model or searchable text corpus would probably still do it, and anything involving programming definitely would. In fact digital humanists have themselves been arguing over whether a humanist has to code to be digital, or if writing and thinking about technology would be enough. This has been framed by some as a dispute between the virtuous modern impulse to "hack" and the ineffectual traditional humanities practice of "yak."

There have now been three volumes of *Debates in the Digital Humanities.* They chronicle many arguments over the relationship of digital humanities to critical theory, race, activism, humanities culture more generally, inclusion, coding, pedagogy, blogging and tweeting, big data, peer review and publication formats, and careers. Harsher external critiques, most notably a 2016 series run in the *Los Angeles Review of Books*, accused the digital humanities of complicity in the evils of neoliberalism (one of the nastiest things you can say to a humanities scholar).[11] Yet very few participants in these voluminous discussions show much interest in exploring the category of digitality itself. They typically treat it as an unproblematic description for modern computerized tools and networks.[12] There are exceptions of course, particularly on the media studies side, but even those critiques have rarely been deeply or rigorously historical.

Matthew Kirschenbaum himself has, as I discussed in earlier chapters, focused intensely on digitality as a category in his own research. Yet in Kirschenbaum's own telling of the story, the initial choice of digital humanities as a new designation did not signal an immediate or general intellectual shift from the established field of "humanities computing." He noted that the reasons behind the term's spread have "primarily to do with marketing and uptake" and it was "wielded instrumentally" by those seeking to further their own careers and intellectual agendas.[13] So why, in the early 2000s, was *digital* close enough to *computing* to work as a virtual synonym yet distinct enough to appear new and exciting? What implicit definitions of

---

[11]"Neoliberal Tools (and Archives): A Political History of Digital Humanities," authored by Daniel Allington, Sarah Brouillette, and David Golumbia. And a response in https://medium.com/@mkirschenbaum/am-i-a-digital-humanist-confessions-of-a-neoliberal-tool-1bc64caaa984.

[12] Even https://dhdebates.gc.cuny.edu/read/untitled-f2acf72c-a469-49d8-be35-67f9ac1e3a60/section/687d2d32-0ec6-4158-b776-ee5cb989ef8b#ch05 which argues for the importance of digging into the affordances and ontology of computing and digital coding disposes of digitality in the first paragraph, in favor of "computational automation."

[13] Cite Kirschenbaum – is this is second piece from the 2012 debates volume.

digitality are hidden in the rhetoric of the digital humanities, and how have they changed over time?

To answer such questions is to move further from the concerns of the first two sections of this book and deeper into the increasingly messy career of digitality as an actors' category within distinct communities. Yet much of what is central to the digital humanities, such as the mining of text corpuses or the provision of online access to sources, is inescapably bound up with longer established and more technical senses of digitality. So in this section of the book our approaches of defining digitality both analytically and historically remain in productive tension with each other. To what extent is the *digitality* of *digital culture*, *digital heritage*, or the *digital humanities* a working through of the fundamental implications of the OD of the 1940s? Are these digitalities closely related, or have the evolved on distinct trajectories? How can the insights of scholars working in these fields help us to reconceptualize digitality itself? What, in short, is digital about the digital humanities? About digital cultures? About digital heritage, digital methods, or digital money?

Dyson, George. *Turing's Cathedral: The Origins of the Digital Universe*. New York: Pantheon Books, 2012.

Gugerli, David. *How the World Got into the Computer: The Emergence of Digital Reality*. Zurich, Switzerland: Chronos Verlag, 2022.

Kling, Rob, and S Iacono. "The Mobilization of Support for Computerization: The Role of Computerization Movements." *Social Problems* 35, no. 3 (June 1988): 226-343.

Negroponte, Nicholas. "Beyond Digital." *Wired* 6, no. 12 (December 1998).

Sax, David. *The Revenge of Analog: Real Things and Why They Matter*. New York: Public Affairs, 2016.

Sterne, Jonathan. "Analog." In *Digital Keywords: A Vocabulary of Information Society & Culture*, edited by Benjamin Peters, 31-44. Princeton, NJ: Princeton University Press, 2016.

Turner, Fred. *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism*. Chicago: University of Chicago Press, 2006.