

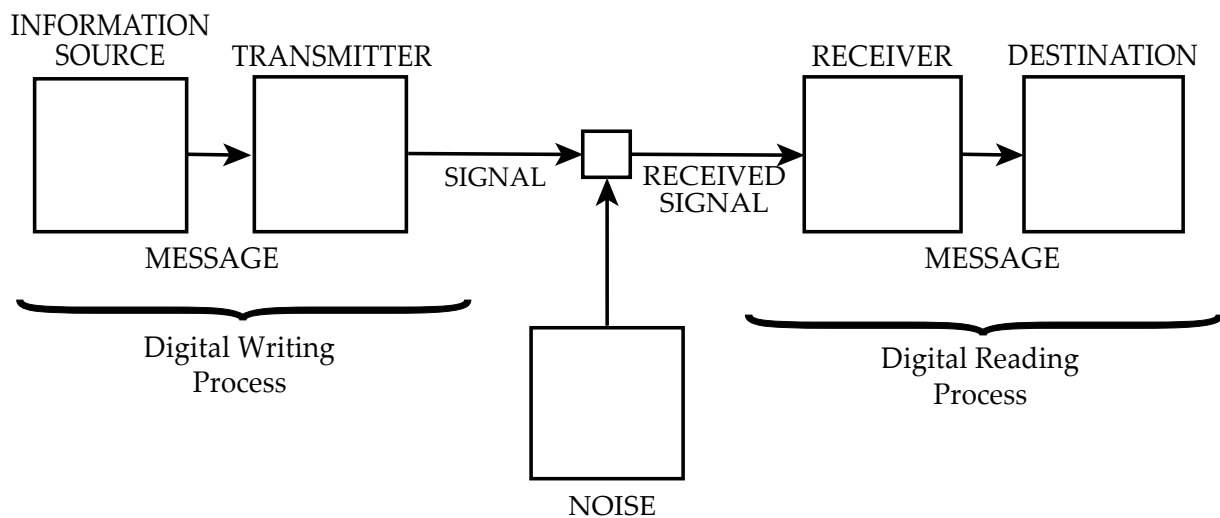


## Defining Digitalities II:

### What's Digital About Digital Communication?

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**Abstract:** 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. This working paper 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.

**Keywords:** Claude Shannon; digital; information theory; Colossus;

In an earlier working paper, Haigh 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, Haigh 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 working paper 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 comput-

ers 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.

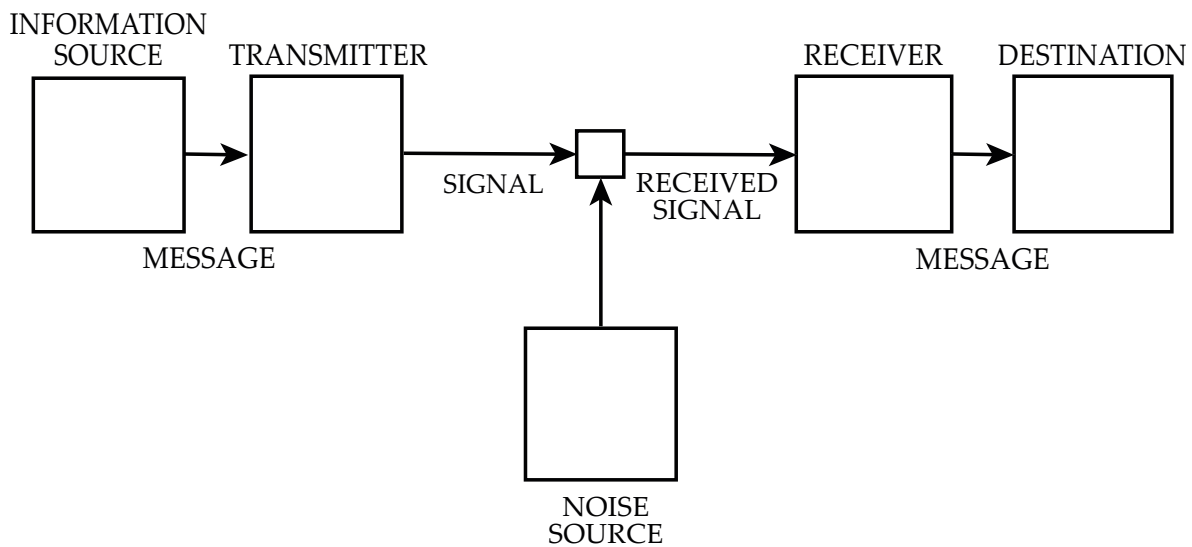


Figure 1: Shannon's schematic representation of a "general communication system" distinguished between the message itself and the signal transmitted after the message had been encoded. Shannon conceptualized the message as a sequence of symbols. The task of the receiver was to interpret the received signal to identify each coded symbol transmitted, thus reconstructing the original message.

## 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 analysis and design of digital signals that carry encoded information. This owes much to Claude Shannon's mathematical theory of communication, or as it was more often called, information theory.<sup>1</sup> Shannon's work on the topic was initially published in his classic 1948 paper, "A Mathematical Theory of Communication."<sup>2</sup> In the decade since the completion of his master's thesis (discussed in Haigh's previous working paper) 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 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.<sup>3</sup>

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 Ralph Hartley and Harry Nyquist from the 1920s onward.<sup>4</sup> 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 the established mathematical terminology of *discrete* versus *continuous* functions – an echo of the choice made 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*.<sup>5</sup>

<sup>1</sup> Ronald Kline, *The Cybernetics Moment, Or Why We Call Our Age the Information Age* (Johns Hopkins University Press, 2015).

<sup>2</sup> Claude E Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal* 27 (July & October 1948):379–423, 623–656.

<sup>3</sup> 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).

<sup>4</sup> Statisticians also began to conceptualize information as something quantifiable during the same period. Kline, *The Cybernetics Moment*, 22.

<sup>5</sup> As Ron Kline has pointed out to us, the term *symbol* was already been established in the mathematical theory of telegraphy, notably in Harry Nyquist, "Certain Factors Affecting Telegraph Speed," *Bell System Technical Journal* 3, no. 2 (April 1924):324–346.

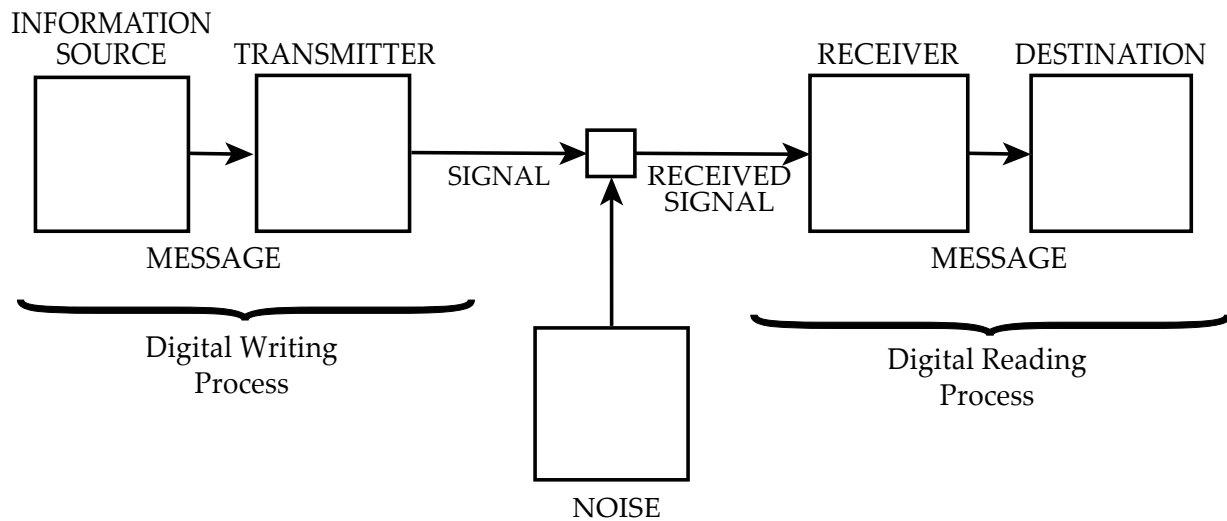


Figure 2: We conceptualize the processes on the left side of Shannon's diagram as the act of writing digitally into a communication channel; we conceptualize the processes on the right side as reading digitally from the same channel.

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 method 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 term 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.

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 informa-

tion content of an analog information source 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."<sup>6</sup> This is why we call Shannon's model of communication fundamentally digital: it can deal with an analog information source only by coding it into a digital signal.

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.

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 Haigh mentioned in his previous working paper, 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.

<sup>6</sup> Claude E Shannon, "A Mathematical Theory of Communication," 47.

## 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 instead of 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.<sup>7</sup> These wartime projects were also 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 Norbert Wiener's "cybernetic vision" in his experiences on the same gun director project that Shannon worked on.<sup>8</sup> Indeed, Wiener's famous book *Cybernetics* carried the alternate title "Control and Communication in the Animal and the Machine."<sup>9</sup> 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."<sup>10</sup>

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: *digital* now applied to all symbols rather than just digits, *analog* to any system of continuous variation, and *information* to anything coded digitally.<sup>11</sup>

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

<sup>7</sup> Kline, *The Cybernetics Moment*, 26–35 discusses the background to Shannon's theory with a particular focus on wartime cryptography.

<sup>8</sup> Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21, no. 1 (Autumn 1994):228–266.

<sup>9</sup> Norbert Wiener, *Cybernetics, or Control and Communication in the Animal and the Machine* (Cambridge, MA: Technology Press, 1948).

<sup>10</sup> 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.

<sup>11</sup> For a close examination of the Postwar development of cybernetics its relationship to the new sense of information see Kline, *The Cybernetics Moment*.

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).<sup>12</sup>

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 of 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

<sup>12</sup> David Huffman, “A Method for the Construction of Minimum-Redundancy Codes,” *Proceedings of the IRE* 40, no. 9 (1952):1098–1101.

and receivers thus introduced a considerable amount of inefficiency into the transmission of Morse code.

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.<sup>13</sup> Shannon discussed ways to select coding schemes to minimize this. He finished by summarizing 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 (and hence correct) these errors. Hamming subsequently developed a comprehensive treatment of error correction and detection which was widely applied in digital computing.<sup>14</sup> 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 based on Hamming’s work, SECDED, allows correction of a single error in each block and detection of two errors. It was deployed by IBM in 1961 to improve the reliability of the memory of its STRETCH supercomputer. Each 72-bit word of memory included 64-bits of data and 8-bits of redundant information.<sup>15</sup> 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).

<sup>13</sup> 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.

<sup>14</sup> Richard W Hamming, “Error Detecting and Error Correcting Codes,” *Bell System Technical Journal* 29, no. 2 (1950):147–160. In these working papers we are adopting a broad definition of information theory, to describe a cluster of approaches initiated at Bell Labs include Hamming’s work on error correcting and detecting codes as well as Shannon’s personal contributions. As Ron Kline has pointed out to us, some participants argued for a narrower definition of information theory. Shannon’s colleague, John Pierce, later bemoaned the fact that “error correction in binary signals has become strongly associated with information theory” because Hamming’s work was tied to the practicalities of “computing and switching machines.” From this viewpoint, Hamming’s work on coding is parallel to information theory but, despite being incorporated into in Shannon’s paper, not part of information theory. J R Pierce, “The Early Days of Information Theory,” *IEEE Transactions on Information Theory* 19, no. 1 (January 1973):3–8.

<sup>15</sup> Charles J Bashe et al., *IBM’s Early Computers* (Cambridge, MA: MIT Press, 1986), p. 452–3.

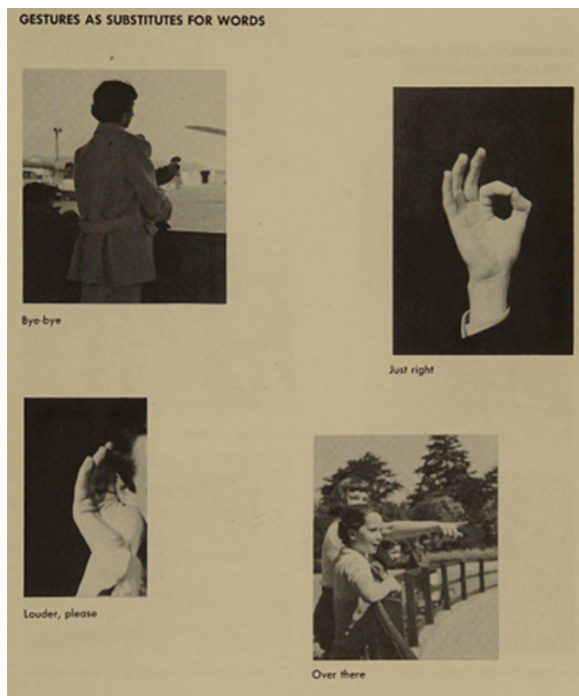


Figure 3: In *Nonverbal Communication* (1956), Ruesch and Kees suggested that some gestures stood in place of words, and thus were recognized as distinct symbols.

### Non-Numerical Digitality

Not all 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.<sup>16</sup> 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).

<sup>16</sup> Thomas Haigh and Mark Priestley, “Colossus and Programmability,” *IEEE Annals of the History of Computing* 40, no. 4 (Oct–Dec 2018):5–17.

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, Shannanesque 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* was not used at Bletchley Park (and was still to be coined). Bletchley Park cryptographers talked not 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 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). 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.”<sup>17</sup> Later in the same book (Figure 3) they suggested that some gestures and facial expressions stood in place of words and hence were recognized as coding distinct meanings.

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.”<sup>18</sup>

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.

<sup>17</sup> Jurgen Ruesch and Weldon 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.

<sup>18</sup> Mills, “Media and Prosthesis: The Vocoder, the Artificial Larynx, and the History of Signal Processing”.



## 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 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 fixed 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 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 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.<sup>19</sup> 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.<sup>20</sup> Just as with the



Figure 4: 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.

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.

<sup>19</sup> Sadie Plant, *zeros + ones* (New York: Doubleday, 1997).

<sup>20</sup> Birgit Schneider, "Digitality", in *Textile Terms: A Glossary* (Berlin: Edition Imorde, 2017):71–75.

The woven portrait (Figure 4) 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.<sup>21</sup>

## Conclusion

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 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 working paper in this series.

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<sup>21</sup> 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.

## References

- Bashe, Charles J, Lyle R Johnson, John H Palmer, and Emerson W Pugh. *IBM's Early Computers*. Cambridge, MA: MIT Press, 1986.
- 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 (1950): 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.
- 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.
- Nyquist, Harry. "Certain Factors Affecting Telegraph Speed." *Bell System Technical Journal* 3, no. 2 (April 1924): 324–346.
- Pierce, J R. "The Early Days of Information Theory." *IEEE Transactions on Information Theory* 19, no. 1 (January 1973): 3–8.
- 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.

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