THE HISTORY OF PUNCHED CARDS

Using Paper to Store Information

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My great-grandfather was in the textile industry in Switzerland. Based on his work creating a portrait of then-president William McKinley using a loom and punched cards, he was recruited by a major American textile firm as a result of the complexity demonstrated in weaving the portrait, and immigrated to the United States. Many years later, my introduction to computers involved the use of punched cards. This personal anecdote illustrates the longevity of punched cards as a storage medium.

Punched cards are small pieces of heavy paper stock that were used in a variety of industries for the control of machinery. This was achieved by punching a series of holes in the cards along a series of rows and columns. When these cards were run through a reading machine, a set of feeler arms (small lightweight pieces of metal) would detect a hole and its location on the card, and make associated changes to the machinery. When a hole was encountered, the feeler arm dropped through the opening and a mechanical or electronic relay on the lever arm closed indicating to the machine that a hole was detected.

One of the first industries to use punched cards was the textile industry starting with the Jacquard loom, first demonstrated in 1801. Looms for producing textiles used punched cards to control both the weft threads and the warp threads. If you are unfamiliar with looms, the warp threads are the threads that are wound back and forth in rows and the weft threads are sent through separations in the warp threads. By using this technique and by frequently changing the color of the thread, intricate patterns could be woven into materials. The use of punched cards was an improvement over the earlier use of paper tape to control the weaving process. Paper tape was first developed by Sir Charles Wheatstone in 1857, and was used to control computers from 1944 to the mid-1970s.¹

Over the period of time punched cards were used, they came in a variety of sizes and layouts and their use became more sophisticated and the patterns that were woven became more intricate. Today, many modern fabrics have the patterns printed on them, instead of woven into them, and an easy way to tell the difference is that woven fabrics appear the same on both sides as the color threads are woven around each other. In printed fabrics, the “inside” of the material usually has a washed-out appearance where only some of the printed color has bled through the material.

Punched cards were used for many years in both the textile industry (1801–present)² and for election voting (1890–2012)³ before they were used for the control of computers starting in the 1940s. Punched cards were also used for timekeeping in businesses. Employees would write their hours for the week onto a punched card and then a keypunch operator,
working on a keypunch machine, would later key the information in by physically punching the appropriate holes in the card. These cards were then used as input to a mechanical tabulating machine or to a computer program running on a mainframe computer. The technique of using punched holes in paper was also utilized in controlling player pianos and fairground organs. Changing the punched roll of paper changed the melody. The use of punched paper was, in itself, an improvement and cheaper than using metal discs to change melodies as found on earlier music boxes and fairground organs. These early metal discs used a series of holes in the metal with raised nibs to pluck a comb with little metal prongs of varying lengths, to produce the musical notes. While this is a different method than was used by punched cards on computers, the basic concept of using holes in a material to control devices was similar.

As mentioned previously, punched cards were used long before the invention of computers. The textile industry was an earlier adopter of punched-card technology and their use was credited to Joseph Marie Jacquard starting around 1810. Jacquard developed a system to control textile machines and to automate the process of switching between different colors of thread by changing the card input. Using this technique, intricate textile patterns could be achieved.

Figure 3.1 A Jacquard loom (photograph taken by Edal Anton Lefterov).
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Heading toward Computers

In the early 1820s, a mathematician and polymath named Charles Babbage used punched cards to control a machine known as the difference engine. The work of Charles Babbage was influenced by the earlier work of Jacquard. This was an early predecessor of today’s computers and it contained many of the concepts that are incorporated into today’s machines such as internal memory and an ALU (arithmetic logic unit). Babbage developed this idea but did not actually build a working machine largely due to funding issues and machinery limitations of the day. The difference engine was followed by several analytical engine and difference engine designs, which progressed in abilities and in simplified designs. Babbage’s son Henry completed the first working Babbage analytical engine after Charles Babbage’s death. Babbage’s first analytical engine design had the ability to produce output on punched cards. Babbage’s designs included several other features that were incorporated into computer programs used on future computers including sequential control, looping, and branching between instructions.

If you were alive and working with computers in the 1960s, 1970s, or 1980s, there is a very good chance that you were exposed to the use of punched cards, which were one of the main ways of inputting data and information into large-scale computer systems of the day. During this era of early computers, the personal computer (PC) was just starting to emerge with revolutionary machines such as the TRS-80, Commodore PET, and Apple 1. With the introduction of PCs, a gradual transition from using punched cards as the primary means for entering data, to the use of keyboards, began. Thus, for the vast majority of people, using mainframe computers was their only exposure to working on a computer and punched cards were the way to enter input and to program the computer. The IBM punched cards were initially designed in 1928 and were used by computers from their inception until the late 1960s. IBM had the largest market share for punched-card sales followed by other vendors such as Remington Rand.

The 1960s and 1970s, then, were the heyday of using punched cards as the primary means of entering data into computers. A less common but still important use was for computer output; the cards used for output were then used for input into another computer program. In this way, computers could produce card output, which could then be used as input for a different computer job; punched cards occupied a unique position in the history of computing as they could be used for input as well as output. They could also be used for storage as punched-card decks could be stored and reused over and over again as long as they did not become damaged. For some applications, the cards were created for a single use only and the cards were destroyed after the processing was completed. Single-use cards were more prevalent in the early use of cards and the use of punched cards for storage became more common later in their history.

Punched Paper Tape

Punched tape was also used during the early history of computing (1940s–1960s) but its use never obtained the volume of punched cards likely as a result of the increased storage and functionality of the punched card. The first use of perforated paper tapes was to control textile looms in 1725 by Basile Bouchon. Early paper tapes were made from a series of punched cards joined together and fed through a machine one after another. The chain of cards was easier to deal with than individual cards for the textile industry. Historically, punched paper tapes were used for telegrams, textiles, stock market “ticker” machines, teletypewriters, and minicomputers (see Braxton Soderman’s essay on ticker tape in Chapter 6).
Other uses for punched tape included newspapers (used until the mid-1970s), early cash registers (1970s), and even reporting baseball scores between stadiums. Over the time it was used, punched tape changed from being a series of connected punched cards to being one long strip of paper. While various standards existed, punched tape typically consisted of either five or eight rows of holes to maintain consistency with Telex machines. The punched paper strips varied in width from three-quarters of an inch to one-inch and were limited to storing only a few characters of data per inch of paper tape.

The paper material that was punched from cards was collected in a bin under the card-punch machines so it could easily be disposed of. The small bits of paper were typically called chads. An interesting reuse of this material was for “ticker tape” parades where the punched out material was tossed from high-rise buildings onto parade routes.

Punched cards had been in use since the 1890s for the U.S. census, but this technology was in use even earlier. For the 1890 United States census, a 24-column card was used. This same format was used up until the 1940 census where a 45-column card was used. Following their use in the 1890 census, punched cards were used by the United States Army during World War I to keep track of medical records and supplies. Insurance companies also used punched cards to track customer data beginning as early as 1896. Large retail chains used punched cards for inventory control and railroads were adopters of punched cards starting in 1896. Railroads used punched cards to track all of their rolling stock and to track merchandise that was being shipped by rail.

The turnpike systems in the eastern United States used punched cards as the primary means to track toll amounts 1940–1983. I remember as a child riding through Pennsylvania with my family and stopping at the first toll plaza to pick up a punched card. This smaller sized card had all of the tollgate information and costs printed on it so that drivers would know how much it would cost to exit the turnpike down the road. These cards were mechanically read at the exit to determine the toll cost. On these family vacations, getting to hold the tollbooth ticket was a close second to the excitement of riding through the Pennsylvania Turnpike tunnels.

What Need Did They Fill?

Although using punched cards for computer input seems awkward and slow by today’s standards, it was a giant leap forward over hardwired computer programming such as was done on the ENIAC (Electronic Numerical Integrator And Computer), considered to be the first general-purpose electronic computer. Before punched cards were adopted, the method used for entering information into computers was via hardwiring. Entering instructions into computers was even more difficult using a hardwired setup:
One of the peculiarities that distinguished ENIAC from all later computers was the way in which instructions were set up on the machine. It was similar to the plug boards of small punched-card machines, but here we had about 40 plug boards, each several feet in size. A number of wires had to be plugged for each single
instruction of a problem, thousands of them each time a problem was to begin a run; and this took several days to do and many more days to check out. When that was finally accomplished, we would run the problem as long as possible, i.e. as long as we had input data, before changing over to another problem. Typically, changeovers occurred only once every few weeks.\textsuperscript{15}

For this generation of computer operators, users, and programmers, the development of punched cards was as exciting as the release of any new technology today. Looking back at this technology, it appears to be highly outdated and inefficient, but at the time it was heralded with announcements such as “The wondrous magic of punch card maintenance of records”.\textsuperscript{16} Punched cards, while obsolete today, “came to symbolize all that was up to date and businesslike”.

**Importance**

Punched cards played an important role in the history of computers and accomplished a feat that will likely never be surpassed. Punched cards were used to control computers for almost 50 years (1950s–2000s).\textsuperscript{17} If you take into consideration the use of punched cards for non-computer use, they have been used for more than 200 years. Pre-dating Jacquard’s loom was an invention by Basile Bouchon in 1725, which used perforated paper rolls.\textsuperscript{18} This means that we are approaching 300 years of use. None of today’s popular technologies are likely to achieve this length of use, as technology changes seem to be happening more rapidly in recent years. Floppy disks were used for approximately 40 years until they were replaced by other, smaller, more durable storage media such as USB sticks.\textsuperscript{19} CD-ROMs, used for storing computer data and applications, came into commercial use in 1985 and remained popular until DVDs emerged in 1995, which were in turn followed by Blu-ray optical disks in 2003. CD-ROMs, DVDs, and Blu-ray disks are collectively known as optical media, the use of which is dwindling, as many new laptops are being shipped without any optical drives. While it is too early to write off this technology, its use in the home is shrinking and being replaced with streaming technologies.

The ubiquitous USB flash drive became popular around the year 2000. Since this time, storage capacity has increased and cost per megabyte has fallen. As of the time of this writing (mid-2017), 2 Terabyte USB flash drives are available. Even with this growth, USB flash drives will be replaced by a new technology down the road such as cloud storage or streaming data. Given the rapid changes in technology and in customer demands, the nearly 50-year reign of punched cards is truly remarkable.

Punched cards were so ubiquitous during this period of time that their look became popular in other areas. The Engineering Research Building on the campus of the University of Wisconsin–Madison was built in 1966 and the window design and the overall shape of the building resembles a punched card standing on end, an interesting interior design in which some offices benefit from having many windows while others have only a few or none.

**Different Types of Cards**

Throughout the years and across various industries, numerous sizes, types, and layouts of cards have been used, with no universal card design. The earliest cards and paper tape used to control textile looms, went through many iterations. While Joseph Marie Jacquard is frequently mentioned as the inventor of this system, his work was an advancement on the
punched-card designs of Jean-Baptiste Falcon, Jacques Vaucanson, and Basile Bouchon. Basile Bouchon is credited as the inventor of paper tape to control textile looms but his design was limited by using paper tape and had a limited number of needles. Jean-Baptiste Falcon modified the initial design and substituted a series of paper cards, which improved the durability of the system. Jacques Vaucanson attempted to have the looms run unattended and, later, Jacquard was successful in achieving full automation.

Herman Hollerith is credited with developing the use of punched cards for controlling computers, and his work was based on the earlier work of Jacquard and Babbage, the latter of which is credited with the origination of the concept of a programmable computer. Herman Hollerith, working in the 1880s, used punched cards and developed a system that detected punches when the cards were passed over a set of electrical contacts using the previously described feeler arms. While Hollerith is fairly well known in the computer industry, credit for the development of a punched-card system for the United States census also belongs to medical doctor John Shaw Billings.

Figure 3.4 The UW-Madison Engineering Research Building, which resembles a punched card standing on end (photo from the author’s collection).
John Shaw Billings developed the initial concept of the punched-card tabulator for the census, while Herman Hollerith is credited as the inventor and builder of the system following discussions with John Shaw Billings. John Shaw Billings was well known as a lover of reading, and had amassed a large personal collection of books (that became the National Medical Library) for which he had developed a tracking system. Billings might have read about the early attempts at replacing hand calculations with mechanical means such as those undertaken by Charles Babbage, Blaise Pascal, and Gottfried Wilhelm Leibniz (who developed a mechanical calculating machine in 1673). According to Chapman:

If there is a single unifying theme in Billings’ illustrious career it is information storage and retrieval; and although he may never have heard the word computer, he was brought to consider ways and means to manage great masses of numerical data by his involvement with the census and with vital statistics.

Billings recalled information that he read on mechanical calculators by Blaise Pascal and Charles Babbage and this information was passed on to Herman Hollerith. In fact, he is quoted as saying to Hollerith “there ought to be some mechanical way of doing this job, something on the principle of the Jacquard loom, whereby holes in a card regulate the pattern to be woven.”
Hollerith took Billings’ suggestion and developed a punched card and an electromechanical system that read the cards and sorted them based on the location of the hole punches. While Billings was concerned with public service and his duties, Hollerith realized the commercial potential and developed the Tabulating Machine Company in 1896. The paths of Billings and Hollerith were not at odds with each other, and it is clear that Billings was well aware of Hollerith’s commercial pursuits. So Billings came up with the initial idea to use punch cards based on earlier work on Jacquard and others, and Hollerith was responsible for the implementation and development, which led to a successful 1890 census and future commercial success. Hollerith’s Tabulating Machine Company merged with three other companies and became the International Business Machines Corporation (IBM).

There have been numerous designs, formats, and uses for punched cards over their 50-year history as a computer input device. While some of these designs have been lost to history, several were popular and widely used in their day. The original IBM or Hollerith cards used for the 1890 and 1910 censuses were 3¼-inch high and 6⅝-inch wide (matching the size of US paper currency) and contained 24 columns of holes. The first four columns on the left side of this design were used to punch in a unique card identifier. The remaining columns could be used for other information. It is interesting to note that these first Hollerith cards did not have anything written on them, unlike the typical computer punched cards from the 1970s and 1980s. Yet even though the cards had no written information, people working with the cards became adept at reading the cards visually.

In a typical card deck of the 1970s and 1980s, the first part of the deck contained control information on what was called control cards. These were used to identify what compiler to use (e.g., Fortran or PL/1), how much disk space to allocate, how much of the core processor to use, and any accounting information. This information on IBM machines was typically written in Job Control Language (JCL). The control cards were followed by the program cards, which were typed by either the programmer or a keypunch operator. A stack of data cards followed the program cards. All of these cards needed to be in their exact order for everything to run correctly.

An interesting variant of punched cards was developed by IBM and was known as the Port-a-Punch. This was a small handheld device that was developed to allow users to enter information onto punched cards manually without the need for a large cardpunch machine. The idea was that manually punched information could be used for recording product sales, taking a physical store inventory, tracking shipment information, or for surveys. This product was introduced in 1958 and was also used by computer operators and by programmers to manually reproduce a card if a card deck failed in the middle of processing, eliminating the need to return to a cardpunch machine to punch a replacement card. The idea was that if a card deck had one thousand or more cards and one was bent, torn, or incorrectly punched, the replacement card could be quickly produced and the processing resumed. Punching was accomplished by placing a new punched card into the small, portable device and then using a stylus that resembled a pen to punch out the holes. The stylus had a small metal tip to help it pop out the chad. The Port-a-Punch device was only slightly larger than a standard Hollerith card, and the cards were pre-scored to facilitate the punching.

Another application of punched-card technology that shows the wide variety of disciplines in which they were used was in the field of corrosion resistance where a system was developed for tracking and quickly locating technical articles. This system used unique punched cards that contained two rows of holes around all four edges of the cards. A classification system was developed, and by punching the correct holes on the cards, technical papers could be classified and quickly located, like an early form of Google Scholar.
This system was known as the McBee system and was used from its inception in the early 1950s until the end of the decade. When a mechanical card reader processed the cards, cards that met the search criteria were physically dropped from the deck, while articles that did not match the search criteria were not dropped.

As mentioned earlier, punched cards found uses in a variety of industries and applications. A common use for punched cards was for bookkeeping. Businesses used punched cards to track corporate data and for input to simple systems that could add, subtract, multiply, and divide. An interesting application that combined technologies of the day was the use of punched cards for tracking magazine subscriptions. The system's punched cards were of a different format and layout than the ubiquitous IBM format. The cards were based on the Remington Rand format with three of the four corners cut off and areas on the card that contained no punches which were used for mailing labels and text. These punched cards could be read by machines and by magazine subscribers, and contained information such as the shipping address, the amount due, expiration date, and type of subscription. When the card was returned from a subscriber, a computer could read it and sort the records by city, state, and subscriber last name. Using this system, records could be filed and sorted much faster and more accurately than by hand-processing. An interesting side benefit, used by the American Nurses' Association, was that the information on the punch cards could be used for additional research. As nurses subscribed to the journal, information was included on what their areas of specialization were. By gathering this new, additional information, research and statistical analysis could be performed to determine statistics such as the percentage of nurses specializing in one area within a given geographic region.

IBM was the leading proponent of punched cards for controlling computers, and during the 1950s, sales of punched cards were responsible for 20% of the company's revenue. While IBM dominated the early computer industry and required the use of IBM-sourced cards for use in their machines, they were not the only player in the punched-card game. Remington Rand Corporation had its own punched-card format, different from the standard IBM format, and the company acquired the Powers Accounting Machine Company, founded by James Powers, Hollerith's co-worker at the Census Bureau. Hollerith and Powers set the stage for the two large companies that would compete from the late 1920s to the mid-1950s. One major difference between the IBM system and the Remington Rand system was that the Hollerith IBM system used electronics to determine the location of punched holes in the cards, while the Remington Rand system was purely mechanical. In some cases, the Remington Rand system might have been superior to the IBM system, in that it was faster and more reliable.

The most commonly used punched-card format was the 80-column IBM card, which were 80-columns wide and 10–12 rows high. Small numbers labeled 1 through 80 were printed on the cards to visually indicate to the card puncher which column was being punched. The first row contained a string of zeros, the second row contained a string of ones, and so on. Representing numbers from 0 through 9 was very simple; if you wanted to start a line with the number 2, the corresponding 2 was punched out. When the feeler arm ran across the opening, an electrical connection was made and the number 2 was entered into the computer.

A–Z characters were slightly more complicated to represent. The top two rows of the IBM card were not labeled, but could be used for control. These top two rows were known as zone rows, and the holes were known as zone punches. The topmost row was known as the Y-row or the 12-zone, and the second row was known as the X-row or the 11-zone. Depending on the card format being used and the character representation, a single character could require
the use of up to six punches within a single column. These characters were based on IBM’s EBCDIC encoding, rather than today’s more common ASCII or Unicode encodings.

The IBM system, including the System 360 mainframe and all of the associated peripherals, was so popular that in the early days of computing, it seemed like there were only two types of machines that people worked on: “a 360” or “something else”. Whatever the “something else” was did not truly matter, as IBM had such a large dominance in the industry. IBM’s 360 held a 65.3% share of the market in 1965, and the closest competitor was Sperry-Rand with 12.1%.31

Two Parts Needed

Two devices were needed in a system, the keypunch machine and the card reader. The keypunch machine was used to punch the rectangular (or round) holes into the punched cards. Keypunch machines contained a hopper that held a stack of unpunched cards, which were then fed individually into an area called a punch station where the keypunch operator would type on a keyboard and the corresponding holes would be punched into the cards. The challenge was to get a completely clean punch and to separate the punched-out material cleanly from the card (the problem of incomplete punches will be described later in this essay). The second piece of equipment needed, the card reader, was the machine that was able to detect the holes in the punched card and to identify the columns and rows of the punches.

Often, computer rooms had a third piece of equipment; a card sorter was used to physically sort the cards into order. By off-loading this process from the mainframe, expensive processing time was saved. A card sorter would take multiple passes to completely sort a deck, based on one field of information on a card. Cards were sorted in order based on the lowest column, then by the second column, etc., in a technique known as a radix sort.32 One of the most popular card sorters of the day was the IBM Type 80 sorter, which had the ability to sort up to 450 cards per minute, and later models were capable of sorting up to 2,000 cards per minute.

The concept that seems most foreign to users of today’s systems is that rarely were any of these pieces of equipment connected, either by wires, or wirelessly; each of the machines was essentially standalone. The programmer could write code on paper at a desk and then pass...
it on to a keypunch operator or punch the information personally. The keypunch machine produced a stack of punched cards that were physically carried to the next device, so there was simply no need to have the machines interconnected. Next, a card reader could be used to check or verify the deck; this machine was also standalone and not connected to the mainframe. Eventually, when everything was checked out, the cards were physically walked over to the mainframe where an attached card reader loaded the information into the computer. Output was either sent to another cardpunch machine or printed on green-bar paper.

My first experience with punched cards occurred while I was pursuing an Associate’s degree in “Business Data Processing” during the early 1980s. I vividly remember typing PL/1, Fortran, and RPG programming language assignments onto punched cards and submitting a deck of cards to the computer operator so they could be run. This process is, of course, very different from writing computer code today, but in some ways it forced programmers to be more thoughtful and precise. Computer code was typically written on paper first and then later transferred to cards through a keypunch machine. If you made a mistake and typed information into the wrong column on the card, the card needed to be tossed out and a new card typed. Often information typed into a wrong column was only discovered after the computer program was run. If a card got torn or bent, it needed to be tossed out and a new card typed. Once your card deck was correct, you carefully walked it over to the operator and tried hard to avoid dropping the deck. By default, the cards were not numbered, so a drop meant that you might have needed to re-punch the entire deck since there was no easy way to see what order the cards should be in. When creating a card deck, you had the option of adding a card number to each card but I remember that this was not commonly done as it was extra work. One trick that was used by some clever programmers of the day was to draw a diagonal line across the top of the card deck. With this line in place, if a deck was dropped, it was fairly easy to put everything back in the correct order, and/or identify where cards were possibly missing.

The computer operator then ran your program in the order it was received by loading your cards into a card reader. Once the job was finished, you would pick up your deck of cards and a printout of the results on green-bar paper. As a student, further problems arose from transporting these cards to and from school in the bottom of a backpack. There were many opportunities for a card to become bent and unusable. One of the fond memories I have from this time was the rather satisfying sound of the card readers. As the cards were mechanically separated and fed into the machine, there was a sound produced that was not unlike the sound of a small engine running. Apparently, I am not alone in the enjoyment of the sounds from punched-card machines; a book review written in 1942 contains the following quote:

Some day, perhaps, a study will be made on the psychological effects of punched-card machines. The aesthetics of the machine, the whirling noises and fluttering columns of figures as the end product, seem to have a fatal attraction for the human mind.33

This complicated and cumbersome process meant that a programmer could only run a program typically once or twice in an afternoon. This is very different from today’s rapid-fire process of changing a line of code, running it, changing something else, running it, etc. Because of the amount of time it took to complete this cycle, programmers tended to be very careful about the code submitted and more time was spent on bench-checking code before even attempting to run it.
This process, while inefficient, had one advantage. The punching of cards could be done on a separate machine without the need to use the mainframe computer. These keypunch machines offloaded the card work and allowed the mainframe to be used solely for processing a computer program. This was a large advantage over the use of hardwiring programs, which effectively kept the mainframe as a single-user machine during both the “coding” and “running” phases. Keypunch machines were relatively inexpensive when compared to the cost of mainframe computers, so offices and schools typically had many rows of keypunch machines available.

**Why Did Punched Cards Fall Out of Use?**

As mentioned above, there were limitations to punched cards, which led to a search for faster and more efficient ways to enter, store, process, and output computer information. Over time, the use of punched-card technology decreased, but replacing this technology was a slow process. The United States Social Security Administration used punch cards up until 1995. Contributing to the decline of punched-card use were problems of storage, cost, and speed.

### Storage

Individually, a single punched card took up only a small amount of space, but collectively the number of punched cards needed to run a program took up quite a bit of space, and the total number of punched cards needed to run a business took up a large amount of space. By 1937, IBM was producing 10 million punched cards each day and this continued until the 1950s when other storage media started being used. Determining the total storage space used by computers today is difficult and estimates vary. In 2017, estimates of the total size of storage needed for all material on the Internet only (not counting personal and business storage not on the Internet) are between 10 and 11 zettabytes and predicted to grow to 20 zettabytes by 2020. Based on back-of-the-envelope calculations made by the author, a 2-inch stack of IBM punched cards contained 508 cards. Each card contains a maximum of 80 characters. (With one byte needed for each character, a punched card could hold, at best, 80 characters.) My 2-inch stack of cards shown in Figure 3.7(b) could contain 40,640 bytes. If we

![Figure 3.7](image-url)

Figure 3.7 (a) Boxes of punched cards in storage; each carton held 2,000 cards. (b) 508 punched cards form a 2-inch stack.
use 10 zettabytes as the size of the Internet storage in 2017, we would produce a card stack 4,101,049,868,766,405 feet or about 776,713,990,296 miles high!

In addition to the space needed, punched cards needed to be stored correctly. The bottom of a student’s backpack was not safe and businesses had similar concerns with the proper storage of cards. Cards needed to be protected from moisture to avoid curling and damage caused by water and mildew. Punched cards also needed to be protected from physically getting bent. A very common phrase that was printed on punched cards, as well as on signs hanging in data centers was “Do not fold, spindle, or mutilate”. While fold and mutilate are rather obvious terms, the term “spindle” has itself become largely obsolete; it referred to a slender metal spike that was used in offices to collect messages and notes by pressing the paper down on the spike. Obviously, punching an extra hole on a punched card was a bad idea; hence the warning. This phrase became so popular that it was used as the name of a movie (an ABC Movie of the Week in 1971), some popular books, and even printed on T-shirts back when punched cards were popular. Another term that was popular in the day was “face down, 9 edge first”. “Face down” meant that the side of the card with the writing on it should be loaded into the card hopper pointing downwards, and “9 edge first” meant that the long edge along the bottom of the card was loaded first. Keep in mind that a single card generally represented a single line of programming code, so if a program contained 2,000 lines of code, 2,000 cards needed to be punched.

**Cost**

While the cost of punched cards was not excessive, they were a business expense and when lower-cost alternatives such as magnetic disks became available, the use of punched cards began to decrease. Some companies had specially designed and printed cardstock, which added to the overall cost. In addition to the cost of originally purchasing cardstock, there was the cost of storage and the cost of replacing bent or damaged cards. In 1995, when the United States Social Security Administration decided to replace their existing punched-card system, it was estimated that they would save $10 million per year. With this kind of potential savings, businesses and governments had to examine alternatives.

**Speed**

Because punched cards used an extra step in the process when compared to today’s systems, there were delays inherent in the system. Even a great typist working rapidly and accurately still needed to wait for the cards to be read into the computer system. Early in the use of punched cards to control computers, the cards were frequently typed twice, by two different keypunch operators. Then the two decks of cards could be fed to a verifier machine that identified cards that were not the same, thus identifying errors before they were even sent to the mainframe. Even with the crosschecking process in place, this only eliminated keypunch errors and not syntax errors in the code. Those error types would only be identified once the program was loaded into the mainframe and run. While, by today’s standards, the cost of having two clerks type identical information and double-check each other seems excessive, in the era when this was done, the cost of clerical help was vastly lower than the cost of a job failing on a mainframe. It simply made economic sense to pay for this overhead. This delay contributed to the demise of punched cards and they were ultimately replaced by direct entry via terminals. No more bent, incorrect, or dropped cards, as data were entered directly into the computer.
Advantages

While both punched cards and punched paper tapes became obsolete for controlling computers, they did offer some advantages over their successors, including longevity. If printed on good paper stock, punched cards and punched paper tape could outlast magnetic tapes. There were several other subtle advantages that punched cards and punched tape provided over modern media used for storage and to control computers. First, was durability; while paper products can be damaged with improper storage and handling, if preserved correctly, punched cards and tape from 50 years ago could be read by machines today. Over time, punched paper strips were replaced with Mylar plastic, which proved to be tougher and more durable than paper strips. Most modern storage uses magnetic media and this is actually less durable over time than punched cards. Magnetic storage can be damaged and become unreadable if the device is dropped and/or if the mechanical arm used to read the disk comes in contact with the storage platter (an accident known as a head crash). Extremes in temperature can also damage magnetic media, as well as strong magnetic fields.

A second advantage of punched cards and punched tape over magnetic storage is that they are visually readable. In the event that a mechanical reader was not available, it was possible for a person to determine what was on a card visually by examining the rows and columns of the punches. This same technique is, of course, not possible with magnetic media.

A last advantage of punched cards and punched tape is that they are easily destroyed. While this might seem contrary to the advantage of durability mentioned above, it actually is a positive. If information needs to be destroyed for security reasons, paper-based storage such as punched cards and punched tape can easily be shredded or burned. Destroying magnetic media is more difficult.

Disadvantages

Punched cards and punched paper tape had several disadvantages when compared to other computer input/output devices. Perhaps the largest limitation is that punched material was single-use; once a card or tape was punched, it could not be altered and needed to be replaced if it was typed incorrectly. Many cards needed to be redone, not necessarily because of incorrect information but simply because the holes were placed in the wrong row or column. Newly emerging magnetic media had a large advantage in that they could be reused multiple times.

Punched cards and punched paper tape had a second large limitation that contributed to their decline as information technology improved; relative to other emerging storage technologies, they had a low information density. In other words, it took a significant amount of paper to store a fairly small amount of information.

Several key problems might have contributed to the decline in the use of punched cards. One of the main problems was discussed earlier. If a card was typed incorrectly or damaged, folded, or bent, it needed to be replaced; no corrections could be made once a character was typed and a hole was punched. If a wrong character was typed, or the right character was typed in the wrong column, the card was useless and a new card was needed. Although probably more legend than fact, stories about programmers dropping a deck of cards abounded at the height of punched-card use in computers. The small paper disks or squares ejected when a hole was punched in a punched card were known as chads, chaff, or sometimes chips. These waste fragments in computer rooms were collected in a bin underneath the keypunch machine. Each chad was roughly ⅛-inch long and when a handful of chads were dropped into your shirt, they became rather itchy (a story for another time).
Partial Punches

While the use of punched cards diminished in IT departments, they were still used in election systems as recently as 2000. Throughout the history of elections in the United States, there has been a level of confidence in the voting process and, with some small exceptions, voters were comfortable that the voting system worked adequately. A punched-card system was behind the controversy in the 2000 United States presidential election. Florida, and other states, used an election ballot commonly known as a Butterfly ballot, the name referring to the ballot’s shape, with the two sides resembling the wings of a butterfly (see Figure 3.8). The idea was to vote for your choice of candidates by punching out a marked area on the card.

During the balloting, pointing devices, about the shape of a lead pencil, were used to punch out the voter’s preferences and these ballots were then read by a card reader machine. In the case of the 2000 presidential election, two problems occurred. First, during the presidential election, some of the chads did not punch out cleanly but were left partially attached. In the popular press at the time, these became known as “hanging chads”. These partial punches were euphemistically called “swinging doors” as their shape resembled a door and they often appear to hang from one hinge. In some cases, the chads were not punched out at all, but the card paper was merely indented. These mistakes were called pregnant chads, dimpled chads, or fat chads. Adding to the confusion at the time, another problem is depicted in Figure 3.8. Because of the confusing ballot design, it was difficult to know which punch-out was meant for which candidate.

Incidentally, the problems that occurred in the 2000 election were not new and the potential issues were known prior to the election. A similar problem occurred in the 1996 election in the state of Massachusetts. Voting systems using these types of punched cards are known as Votomatic systems and had higher error rates than other systems that were available at the time, and they also had a higher impact when it came to voters with lower levels.
of education and among poorer people. The irony of this entire 2000 presidential election problem is that while the punched cards contributed to the problem, at the same time, they provided a perfect audit trail in that the original cards could be reexamined by hand. This is not the case with forms of electronic voting.

A common problem for punched-card programmers was when a card was nearly perfect with the exception of one extraneous punch. Typically, this extra punch would make a card effectively useless and the official solution was to completely re-punch the card. Since re-punching a card was annoying and time-consuming, some enterprising programmers discovered that a previously punched chad could be placed into the extra hole. By using a soft lead pencil and lightly scribbling over this chad and the edges of the hole, the replacement chad would stay in place and make it through the card reader. This was only a temporary fix but it demonstrated the inventiveness of the programmers at the time.\footnote{41}

\section*{Current and Future Uses}

As surprising as it might be, punched cards have not totally disappeared from the computing landscape, as their use in voting machines demonstrates. Punched-card systems were initially used for voting during the 1964 elections, and some are still in use. As recently as 1996, 37.3\% of United States voters voted using a punched-card system. By 2012, only .02\% of the United States voted using punched-card systems, which was limited to four counties in the state of Idaho. This conversion was largely the result of the aforementioned debacle during the 2000 U.S. presidential election. This decrease to .02\% is a dramatic change from the 2000 presidential election, where 32.1\% of the voters in the United States used a form of punched cards for voting, making this technology the most widely used one in the election. Punched-card ballot systems are being replaced with newer methods including mark-sense ballots and systems where the vote is directly recorded into a computer system.

The current use of punched cards was recently detailed in an article on a small manufacturing company in Texas.\footnote{42} Sparkler Filters of Conroe, Texas currently (as of early 2017) uses an IBM 402 system that uses punched cards. Several reasons are given for the continued use of punched cards in the business, but when a large computer system is in place and works effectively, it can be expensive and troublesome to switch to a new system. Basically, “if it works don’t fix it” applies.

What’s old is what’s new; after more than 50 years, the basic concept behind punched cards could be used once again in computers. An emerging technology being developed by IBM creates holes in polymer material at a density of a trillion bits per square inch.\footnote{43} The end result of this technology is that information can be stored in an extremely small space but the system is basically the same as a punched card; a hole in the polymer represents a zero in the data and the absence of a hole is used to represent a 1. This project is known as “IBM Millipede”, and while it might never see the light of day as a commercially available product, it does leave open the door for the possibility of future “punched” technology. Potential advantages of this technology are very fast read and write rates compared to flash memory and very high data density rates.\footnote{44}

Punched cards are still used today on knitting machines such as those manufactured by Brother, Elna, and PASSAP to control patterns in the stitches using methods similar to the original Joseph Marie Jacquard system devised more than 200 years ago. Punched-card sets that produce woven patterns are readily available and some new machines from manufacturers such as PASSAP, are still commercially sold.

Punched cards are also still a popular option for retail businesses to track customer loyalty. Small business-card sized pieces of paper are handed out and every time an eligible purchase
is made, a uniquely shaped punch is entered on the card. When the punches are complete, the customer receives a discount or a free item. One drawback of this approach is that the paper punched cards can easily be lost or misplaced which results in a less than satisfying experience for the customer and potential lost sales for the business. This use of punched cards is slowly dwindling with bar-coded tags for key rings, which in turn is slowly being replaced by the use of smartphone apps.

Punched-card use had a long life during the history of computing and could have new uses in the future. Just as computer scientists at the beginning of the computer age repurposed existing punched-card technology from other industries, punched cards might not be done yet. For computer scientists and business users, punched cards played a large and vital role in getting technology to where it is today. Knowledge of this era in computer history is beneficial as we look forward to future advances in technology.

Notes
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