Chapter 4

Punched-Card Machinery

Introduction

From quite early in the twentieth century, until the advent of moderately priced electronic computers in the late-1950s, the bulk of the automatic data processing needs of commerce was met by punched-card machines. There were two main strands in the development of these machines, which are described in this chapter.

The first strand was the development of census machinery in the United States. Beginning in the early 1880s, Herman Hollerith (1860–1929) developed a range of equipment for the mechanical tabulation of the 1890 United States census; this machinery saw several improvements in the censuses of 1900 and 1910. From this point, however, the Bureau of the Census increasingly adopted the commercially manufactured punched-card machines it had helped to originate.

The second strand was the commercial development of punched-card machinery. Hollerith realized, from an early date, the statistical and accounting possibilities of his machines in commerce and incorporated a company to develop and supply suitable equipment. From this beginning, between the two world wars a large-scale industry developed that came to be dominated by IBM. The machines themselves evolved in complexity out of all recognition from the original census machines, and applications blossomed in statistics, accounting, and science.

Finally, with the advent of the stored-program computer in 1945, punched-card machine technology underwent a twenty-year transformation, during which the products of the industry were turned into electronic data processing computers.

The Development of Census Machinery

The Census Problem

The first United States decennial population census took place in 1790, when the recorded population was a little under four million. The early censuses were comparatively simple affairs: only a few inquiries were made of the head of each family, and the published census reports were modest in scope. By 1850, however, the population had increased by more than a factor of five and many more inquiries were made of every citizen; furthermore the number of tabulations, as measured by the size of published reports (1,605 pages in 1850), had grown considerably.

In the 1850 census, for the first time, the tabulation was performed by the method of "tallying." In essence, tallying involved examining each questionnaire (or schedule) returned for a census district and recording a mark on a tally sheet for each fact, or combination of facts, to be tabulated. Totals for larger sections of the population were then determined by adding the counts from individual tally sheets. At first this process was entirely unmechanized. In the latter part of the 1870 census, and in the 1880 census, a very limited degree of mechanization was provided by the Seaton device. This simple contrivance enabled several tally sheets, combined on one length of paper, to be brought conveniently close together. Notwithstanding the help of the Seaton device, the 1880 census took about seven years to process. Given the influx of immigrants that was then occurring—it was expected that the population of America would perhaps double in the next decade—it was evident that in the next census either the scope of the inquiry would have to be curtailed or a method of mechanical tallying introduced.

Herman Hollerith, then employed at the Census Bureau, thus became aware of the population census problem. Hollerith, a graduate of the Columbia School of Mines, New York, had been engaged in the collection of industrial statistics since joining the bureau in the fall of 1879. In 1882, he resigned from the Census Bureau, spending a year as an instructor in mechanical engineering at MIT followed by a short period as an examiner in the United States Patent Office, after which he became an independent patent agent. During these years he worked on both a tabulating system and railway braking systems. A patent application was made in 1884 for an early form of tabulating system based on a punched paper tape, and patents for a card-based system were filed in 1887. Conflicting accounts of the origination of the idea of using a punched-card medium appear in the literature. The idea may have been suggested by a senior member of the bureau staff, J. S. Billings; alternatively, Hollerith may have derived the idea from the Jacquard loom, or the method of punching a physical description of a railroad passenger in his ticket (Hollerith in fact used a conductor's punch to perforate cards in early trials of the system). In any event, the development of the idea was entirely due to Hollerith.

From 1887 a number of trials of the system were made, compiling mortality statistics for Baltimore and other cities and medical statistics for the Office of the Surgeon General of the Army. The major trial for the tabulating system came in 1889 when the director of the census, Robert P. Porter, organized a competition to select a tabulation system for the 1890 census. Three competitors submitted entries: in addition to Hollerith's system, there was another system based on paper "slips" and another based on cardboard "chips." Both of the systems of Hollerith's competitors involved the transcription of schedule entries on to paper slips or cards, which were then repeatedly sorted and counted by hand, quick identification being facilitated by color coding. The contest involved the recording and tabulation of the schedules for the St. Louis district from the 1880 census, representing something in excess of ten thousand individuals. The Hollerith system was a convincing winner: the recording of data was significantly faster than either of his competitors, and tabulation was up to ten times as fast. The reason for the speed of the Hollerith system was that, unlike the other systems, once a card had been punched, all manual tallying and sorting was eliminated.

The Hollerith Electric Tabulating System

The Hollerith Electric Tabulating System consisted of several pieces of apparatus in addition to the tabulating machine itself. The tabulation of the census involved three distinct processes: the recording, tabulation, and sorting of data.

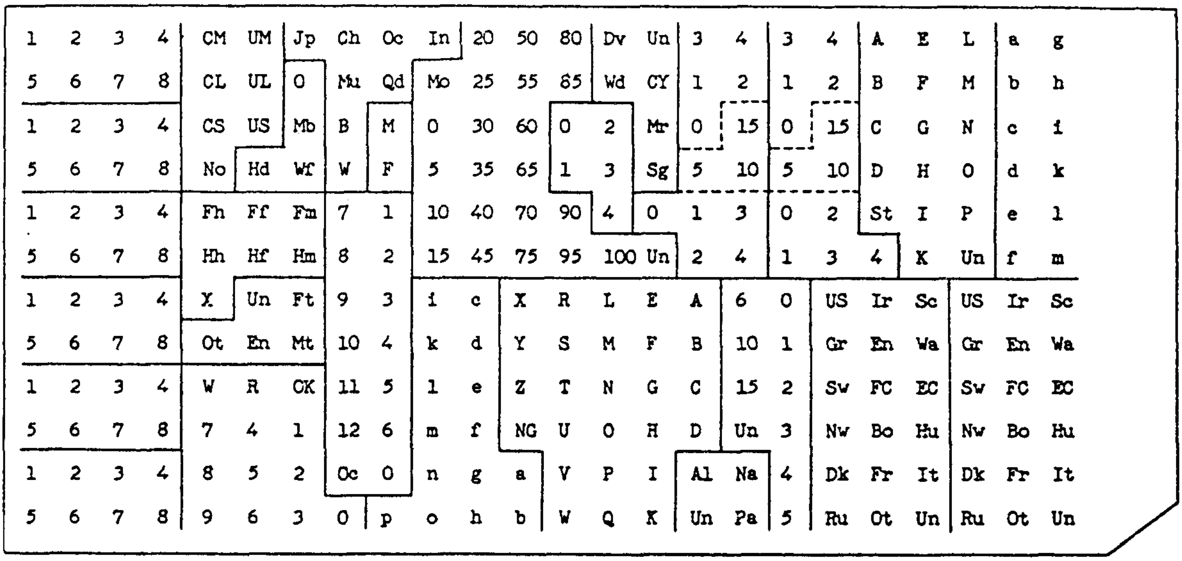

Figure 4.1. Form of the 1890 census card.

Each schedule returned in the census contained the information for a complete family. From this schedule one card was punched for each person.

Figure 4.1 illustrates the form of the card: each $6^5/8" \times 3^1/4"$ card had 288 punching positions and was corner-clipped to ensure the correct orientation. The leftmost 48 punching positions contained the four-digit code of the census "enumeration" district; because a complete batch of schedules for a district was punched together, the district number was "gang punched" identically on each card. The gang punch (Figure 4.2) was a lever-operated device in which the pattern of holes was set up by an arrangement of metal slugs, and up to six cards could be perforated in one stroke.

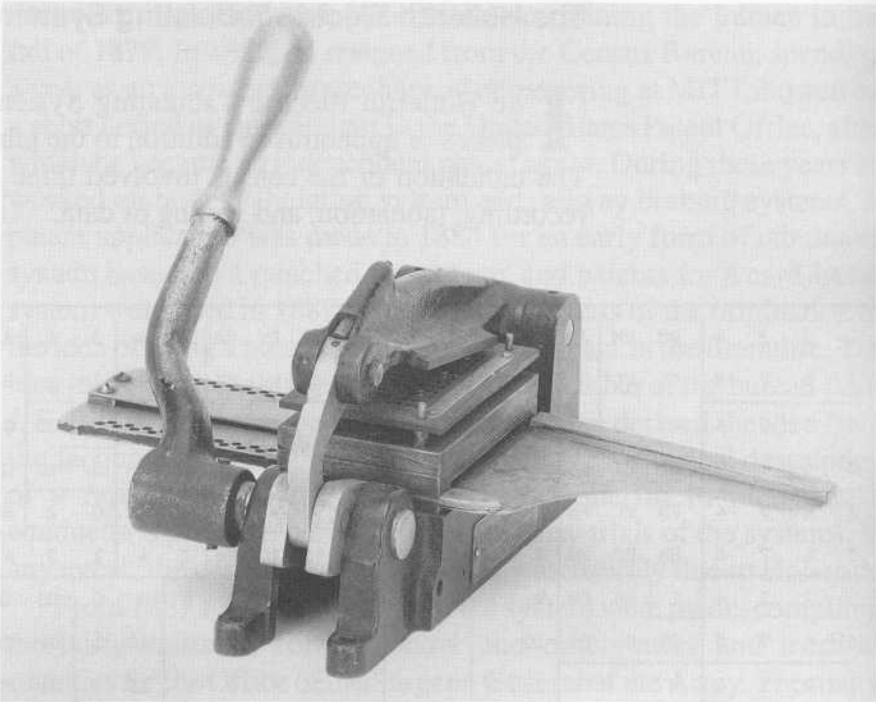

Figure 4.2. Gang Punch. Courtesy Smithsonian Institution. Photo No. 64550.

The data for an individual was recorded in the right-hand 240 punching positions of the card. Data items were recorded in a number of irregularly shaped regions, or fields, on the card, starting at the top left and moving approximately clockwise around the card. The third field, for example, recorded the racial type of the individual (Japanese, Chinese, Octoroon, Indian, etc.). The fourth field recorded gender (male, female). The fifth field recorded the five-year period in which the age of the subject fell (0-4, 5-9, 10-15 . . . 100-plus) and the sixth field the unit within the five-year period. The seventh field recorded "conjugal condition" (unmarried, married, divorced, widowed). And so on round the card for a total of twenty-one fields.

The data was recorded using the pantograph punch (Figure 4.3). The punch had a drilled guide plate bearing an image of the card to the front and a carriage for a blank card to the rear; by depressing an index pin into a hole in the guide plate, a hole was punched with accurate registration in the corresponding position in the card. It is interesting to note that, unlike later card-punching practice, data was

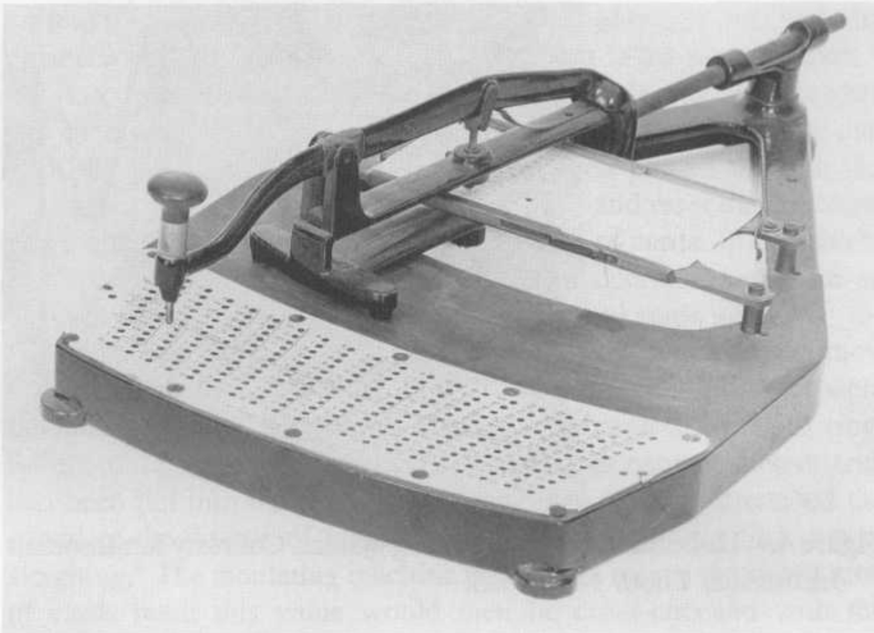

Figure 4.3. Pantograph punch. Courtesy Smithsonian Institution. Photo No. 64551

not transcribed literally onto the card but had to be interpreted by the operator. Thus, an age of 57 (say) would be recorded as a hole in the corresponding five-year period (i.e., 55-59) and a second hole in the additional units (i.e., 2). Similarly, the place of birth was recorded as a two-letter code in fields 10 and 11, for which a code list was supplied (e.g., "Ag" for Connecticut, "Ka" for Germany—the codes had some, but not much, mnemonic significance). Because the order of fields clockwise around the card was the same as the order of the schedule inquiries, the punching operation was quite smooth flowing and operators averaged seven hundred cards per day. In the 1890 census, plain manilla cards were used, so that a "reading board," bearing a printed image of the card (as in Figure 4.1) enabled cards to be read back for verification by another person.

The tabulating machine (Figure 4.4, left) was used to count the number of holes, in selected positions and in selected combinations, of a batch of cards passed through it. The machine contained a maximum of forty clocklike counters, each capable of registering up

Figure 4.4. Hollerith electric tabulating system. Courtesy Smithsonian Institution. Photo No. 64563.

to 9,999. Cards were sensed by a hand-operated press that bore 288 spring-loaded pins: when the "pin-box" was brought down onto a card a pin encountering a hole would pass through, dip into a mercury cup, and complete an electrical circuit; but if the pin met solid card, it would simply be pressed back and no circuit would be completed. A counter included in the circuit would thus be incremented by one, or not, depending on the presence or absence of a hole.

The simplest operation the tabulating machine could perform was to count the number of holes in selected positions in a batch of cards. Thus, in principle, if one counter was wired to register males and another to register females, the effect of passing a batch of cards through the machine would be to obtain the total number of males and females represented. Invariably, actual counts were much more complex so that as much information as possible could be extracted in a single passage of the cards through the machine. For example, in the first count of the census, the male and female populations were classified by "color-nativity" and tenure for different age groups using the full forty counters.[1] Each combination was achieved by wiring relay circuits. For example, one counter was required to register the total number of native-white persons aged 45-plus; therefore, the counter was wired into a relay circuit that passed a current if one of the holes 45, 50, 55 . . . 100-plus was punched, the citizen was white, and both parents were born in the United States.[2]

A counting operation would begin by resetting all the counters and then reading the cards for an enumeration district one-by-one with the press. When all the cards had been passed through the machine a supervisor would record the totals and reset the counters, and the operator would begin the next batch of cards. Impressively fast speeds could be obtained by a skillful operator, and even an average operator managed eight to ten thousand cards a day.

The tabulating machine had several measures to ensure accuracy. For example, when the cards of a given enumeration district were tabulated, sensing the correct district code caused a bell to ring; failure to ring indicated that a card from another enumeration district had been put into the pack. A contemporary reporter described the sound of the dozens of machines as "for all the world like that of sleighing." The tabulating machine would also record the grand total of cards read; this value would then be cross-checked with the subtotals of the different classifications, although discrepancies of one or two units were usually tolerated.

After the first count, succeeding counts determined finer statistics for smaller divisions of the population. For example in the second count, for conjugal condition, it was required to determine, for each sex of the seven racial types, marital status classified by age. First the cards had to be sorted into the seven racial groups. This sorting process was achieved using the sorting box, as a by-product of the first count.

The sorting box (Figure 4.4) consisted of approximately two dozen compartments each having an electrically operated lid, normally kept closed. By an appropriate relay circuit, of an identical type to that used for the counters, a combination of holes could be used to select a compartment whose lid would fly open when a card of the right type was sensed. The operator would drop the card into the offered compartment and close the lid. The fact that only one lid opened eliminated the possibility of the operator placing the card in the wrong compartment; closing the lid with a deft tap took almost no time.

The Hollerith tabulating system achieved its superiority over a manual system in a number of ways. First, it enabled as many as forty complex combinations to be counted in a single handling of the cards; this was far more than was possible in a manual system and was the most decisive advantage of the census machine. Second, the Hollerith system eliminated a great deal of the physical sorting and counting of records of a manual system; thus the sorting box was always used alongside the tabulating machine, presorting cards for a subsequent count with the minimum cost in time and handling. Third, the Hollerith system was inherently more accurate than a manual system because the possibilities of incorrectly sorting and counting were greatly reduced.

Further Census Developments

The tabulation of the 1890 census was a technical and financial triumph for Hollerith. It was well reported in the press, appearing for example as the main article in the August 30, 1890 issue of *Scientific American* (Figure 4.5). Within six weeks of the start of the census, the rough count of the population was complete (total 62,622,250 citizens). This achievement was only a partial vindication of the Hollerith system because the rough count was produced not by using punched cards but by registering family counts directly into the tabulating machines using a simple keyboard. After the rough count, the detailed tabulations began for which nearly sixty-three million cards had to be prepared, one for each citizen. Altogether, seven counts were made involving several hundred million card passages through the census machines. The census was completed in a little over two years, a great improvement on the previous census, and much more complex and refined tabulations were produced (the published reports of 10,220 pages were nearly twice the length produced for the previous census). Approximately one hundred

Figure 4.5. Cover of the *Scientific American*, August 30, 1890. This evocative engraving shows scenes from the 1890 U.S. population census. *Bottom*: The incoming completed schedules are received and assembled for onward processing. *Top right*: Schedules are punched onto cards using the pantograph punch. *Top left*: Using the census machine, the cards for an enumeration district are tabulated and deposited one by one into the sorting box. *Center*: Using a special keyboard, family head counts are entered for the rough count. Courtesy Smithsonian Institution. Photo No. 47941.

SCIENTIFIC AMERICAN

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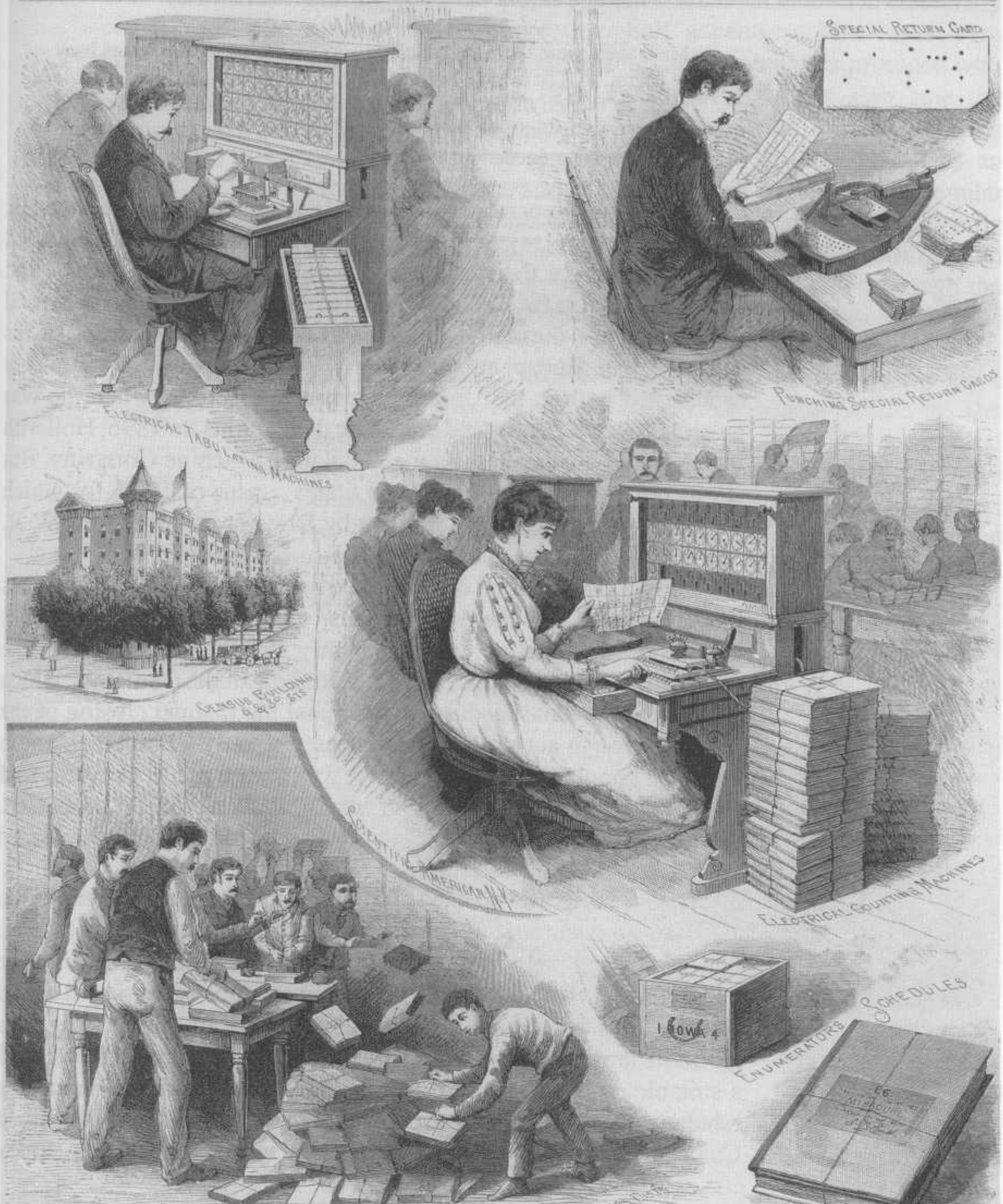
A WEEKLY JOURNAL OF PRACTICAL INFORMATION, ART, SCIENCE, MECHANICS, CHEMISTRY, AND MANUFACTURES.

Vol. LXIII.—No. 9. ESTABLISHED 1845. | NEW YORK, AUGUST 30, 1890. | $3.00 A YEAR. WEEKLY.



THE NEW CENSUS OF THE UNITED STATES—THE ELECTRICAL ENUMERATING MECHANISM.—[See page 132.]

census machines were used and several hundred pantograph punches, all of which were maintained by Hollerith and his assistants. The machines evidently needed regular repair and maintenance, but it is possible that the faults were not entirely mechanical:

> Mechanics were there frequently . . . to get the ailing machines back in operation. The trouble was usually that somebody had extracted the mercury (which made the necessary electrical contacts) from one of the little cups with an eye-dropper and squirted it into a spittoon, just to get some un-needed rest.[3]

While the preparations for the 1890 census were underway, Hollerith received several inquiries from European countries that led to the adoption of the system for the 1890 censuses of Austria and Norway, and also for Canada nearer to home. Hollerith made several trips to Europe during the mid-1890s consolidating the use of his machines in European censuses. His reputation was quickly established both in the United States and in Europe, where he was awarded several honors and academic distinctions. In 1896, Hollerith incorporated his business as the Tabulating Machine Company. But it was not until the twelfth United States census of 1900, for which Hollerith was awarded the contract by Director of the Census W. R. Merriam, that his machines saw large-scale use again.

The 1900 population census relied for the most part on the census machines used for the 1890 census, although their number was increased considerably. An apparently simple improvement, the automatic feeding of cards, was made to some of the tabulators, which eliminated the hand feeding of cards and the manual closing of the press. Although automatic feed was used to only a limited extent in the 1900 population census, when it was used it made a several-fold improvement in the speed with which cards could be processed. Automatic card feeding eventually was provided in all punched-card machines.

The most significant change of punched-card machine use in the 1900 census occurred with the tabulation of the census of agriculture, which required the accumulation of quantities (such as the number of bushels of wheat produced on each farm). This necessitated a card capable of storing numerical quantities, and an "integrating" (as Hollerith termed it) tabulator. In fact, Hollerith had already developed a suitable multicolumn card format and a small reliable integrating tabulator that was then in use with the New York Central Railroad Company (see next section). A new punching machine, the key punch, was introduced for the punching of the agricultural census cards. This device was a great improvement on the pantograph punch in that cards could be punched far more rapidly using the calculator-style key pad (Figure 4.6). The keypunch was manufactured in essentially the same form for more than half a century. The cards were summarized by large, hand-fed integrating tabulators provided with ten adding units. The 1900 agricultural census also saw the introduction of another important advance, the electrical sorting machine. This machine enabled sorting to be carried out as an independent operation, and not merely as a by-product of regular tabulation with the census machine. Prior to the advent of the electric sorter, sorting could only be achieved by "needle sorting"—an awkward operation that entailed poking a blunt needle through the holes in a stack of cards, to isolate groups of cards with common hole punchings.

Once again the census, completed in approximately two and a half years, was a technical and financial success for Hollerith. The Tabulating Machine Company supplied over three hundred tabulating machines and more than sixteen hundred pantograph and key punches. The company, however, was not awarded the contract for the 1910 census, because Hollerith was unable to agree on financial terms with the new director of the census, S. N. D. North.

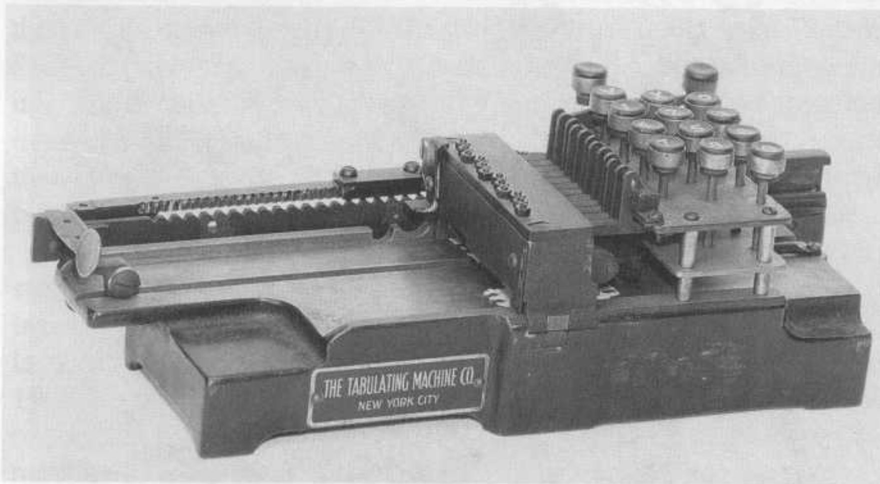
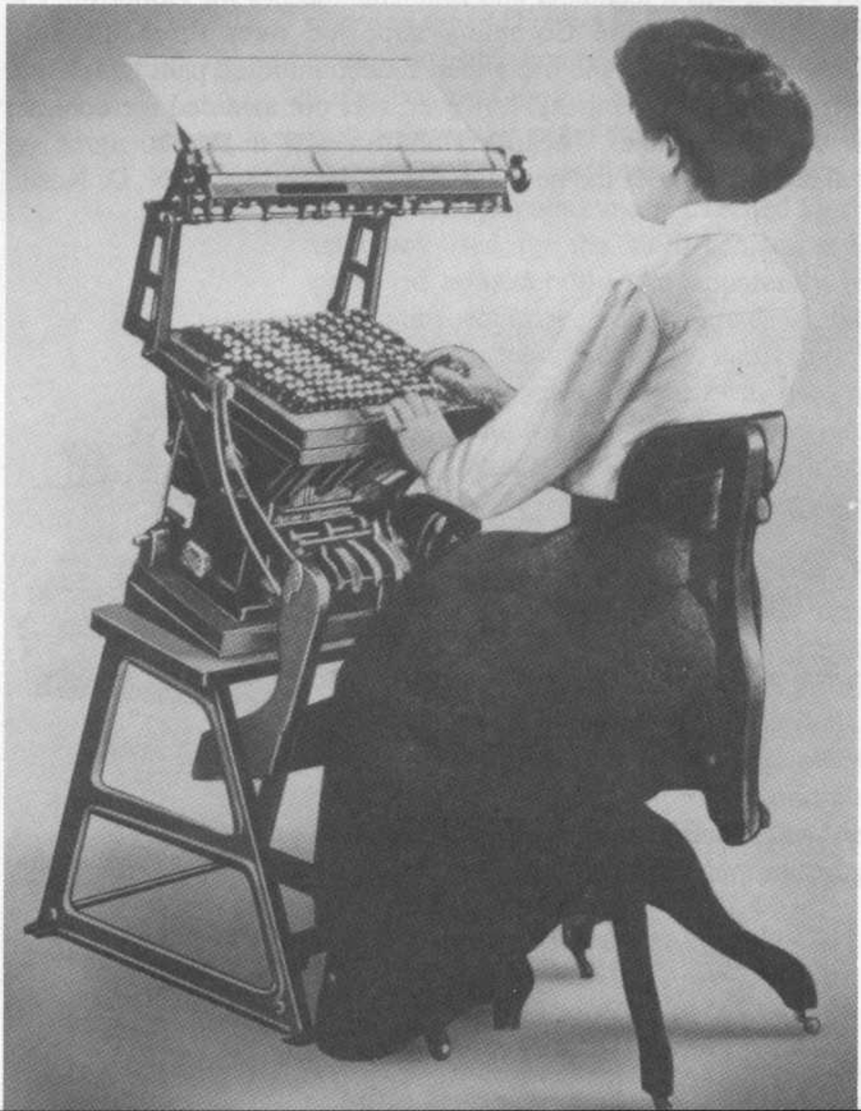


Figure 4.6. Hollerith key punch used for the 1900 U.S. census.
Courtesy Smithsonian Institution. Photo No. 64549

In 1905 Hollerith severed his connection with the Bureau of the Census and from that point put all his energies into developing the commercial application of punched-card machines.

In the meantime, Director North established a census machine shop to improve and develop new equipment for the forthcoming 1910 census. The most notable improvement to the system was the incorporation of printing counters in the tabulators; these eliminated the copying down of the counter dials, which was both time consuming and a potential source of error. In 1907 a mechanical expert, James Legrand Powers, was employed to improve the key punch. The result was an entirely new device (figure 4.7) that

Figure 4.7. Powers key punch, 1910 U.S. census. Courtesy ICL Historical Collection.



was electrically powered and had an automatic feed which resulted in much faster operation; a complete card was set up prior to the punching operation so that corrections could be made without repunching an entire card. The new punch also had gang punching and simple sorting facilities. Powers was also involved in making substantial improvements to the sorter that Hollerith had supplied for the 1900 census. Hollerith sued the Bureau of the Census for patent infringement, but the case was not clear-cut and after two years the action was dropped by mutual agreement. In 1911, Powers left the employ of the Bureau of the Census to establish the Powers Accounting Machine Company, an organization which proved to be a serious competitor for the Tabulating Machine Company.

Commercial Development of Punched-Card Machinery

Development of the Punched-Card Machine Industry

During the early years of the Tabulating Machine Company, which Hollerith had incorporated in 1896, the company operated in a comparatively small way on two fronts. First, it supplied census machinery to the United States Bureau of the Census and to the census organizations of other countries, particularly in Europe. Second, it attempted to supply tabulating machinery for commercial use. The cyclical nature of the census business—censuses were taken in the first or second years of the decade almost everywhere—meant that Hollerith needed to look for other, noncyclical, uses for his tabulating machines in order to stabilize the revenues of his business.

Initially, the commercial use of tabulating machines was on a very small scale—a few machines were supplied for the compilation of insurance and railroad statistics. Hollerith was not able to interest a large-scale user, the influential Pennsylvania Steel Company, until 1904. Following the loss of the Bureau of the Census contract in 1905, commercial work became the mainstay of Hollerith's company; the machines themselves evolved rapidly and their use increased greatly, particularly by railroad companies. By 1908, the Tabulating Machine Company had about thirty customers, including railroads, utilities, manufacturers, and government agencies. Thereafter the revenues (and therefore the customer base) grew at the rate of about 20 percent every six months.

By 1911 the Tabulating Machine Company had expanded to a size that exceeded Hollerith's ambitions. Aged 51 and not in strong health, he stepped down as general manager and allowed the company to be acquired by a well-known business promoter, Charles Flint. American business was then caught up in one of its periodic merger waves, and Flint formed a new organization, the Computing-Tabulating-Recording Company (C-T-R) by consolidating three principal concerns. These were a manufacturer of computing scales (i.e., machines that weighed an article and calculated the cost in one operation), the Tabulating Machine Company, and a manufacturer of time recorders (i.e., machines used for recording the "clocking on" and "clocking off" time of employees). Each of these companies was recognized by one word of the new title: Computing-Tabulating-Recording. C-T-R expanded rapidly, achieving some economies of scale both in selling costs and in manufacturing, and it also had the greater security resulting from diversification. Hollerith remained a director for a year or two, and a technical consultant until 1921, when he retired.

In 1911, the year in which C-T-R was formed, James Powers incorporated the Powers Accounting Machine Company. The company developed a range of commercial punched-card machinery considerably superior to that offered by C-T-R, in particular offering a printing tabulator that was far better suited to commercial applications. For the first time, machines competitive with the Hollerith system had appeared on the market.

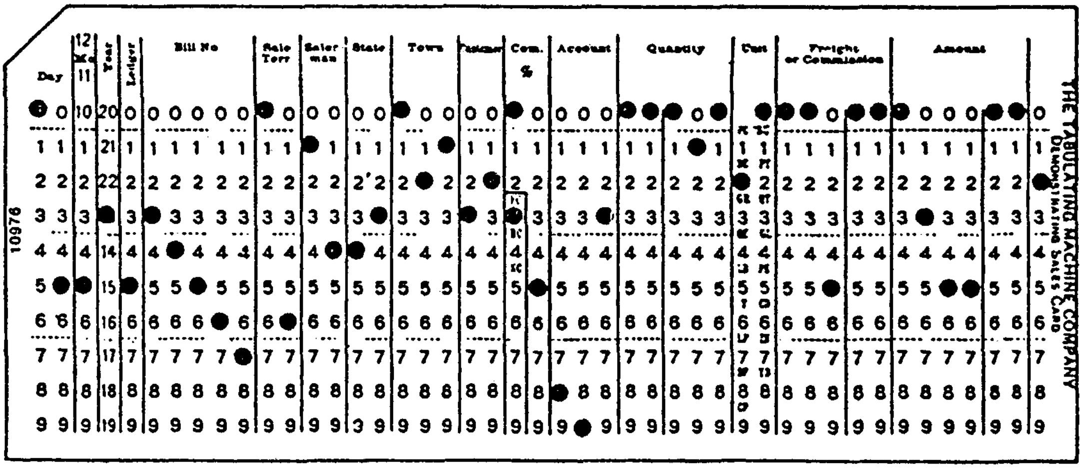
It is fair to say that there were three key figures in the development of the punched-card machine industry: Herman Hollerith, James Powers, and Thomas J. Watson. Watson (1874-1956), who became president of C-T-R in 1914, was a man of a completely different mold from Hollerith and Powers; he considered himself foremost a salesman. He had already had a meteoric career with the National Cash Register Company, and brought much of its sales-oriented culture with him to C-T-R. Watson immediately realized that the tabulating machine division was the most promising part of the company, but that its products were inferior to those of the Powers company. A research department was set up under E. A. Ford—Hollerith's principal coinventor—whose staff would soon include such outstanding inventors as J. W. Bryce, C. D. Lake, B. M. Durfee and F. M. Carroll. Products to match the competition soon followed. Under Watson's leadership the company had trebled in size to well over three thousand employees by 1924, when the name was changed to International Business Machines (IBM).

As in the United States, the punched-card machine industry in the rest of the world was based on the exploitation of, and competition between, the Hollerith and Powers patents. In Europe for example, the British Tabulating Machine Company (BTM) was formed in 1907 in London with an exclusive right to manufacture and market Hollerith machines in Great Britain and its Empire.[4] In 1913, the Accounting and Tabulating Machine Corporation of Great Britain was formed to market the Powers machines; the British Powers company soon became independent of the American parent and developed many of its own machines. Competition between the two British companies was intense. Continental Europe also had a thriving tabulating machine industry: in Germany the Deutsche Hollerith Maschinen Gesellschaft (usually known as *Dehomag*) was formed in 1910; this company developed several important patents that C-T-R acquired when it took a 90 percent stake in the company in 1923. C-T-R also established a French sales organization, Société Internationale des Machines Commerciales (later IBM France). In both of these countries, as in other European countries, the Hollerith and Powers lines competed. Europe also had its own indigenous manufacturers: Machines Bull in France, and Soviet Russia also produced machines. By the mid-1920s, IBM, Powers, or BTM outposts were to be found beyond Europe and the United States in most developed corners of the globe. Even so, although punched-card machines were important and pervasive, the industry was quite a small one and quite minute by comparison with the present day computer industry. For example, by the end of the 1920s IBM had only about three thousand customers in America—this has to be compared with the hundreds of thousands of computer installations it has today; again, IBM's annual revenues were then only about twenty million dollars compared with about fifty billion dollars in the mid-1980s; similarly, its head count has risen perhaps one hundred times from the three thousand it had in the late 1920s.

The Powers Accounting Machine Company of the United States was itself the subject of a merger in 1927, when it was acquired by the Remington Rand Corporation. As a result of the fierce competition between IBM and Remington Rand the machines developed very rapidly: the tabulating machines produced in the 1930s contained several thousand precision components, and were among the most complex of manufactured devices.

In spite of the Great Depression of the 1930s, the punched-card

Figure 4.8. Evolution of the punched card: (a) 45-column TMC card, (b) 80-column IBM card, (c) 90-column Remington Rand card.



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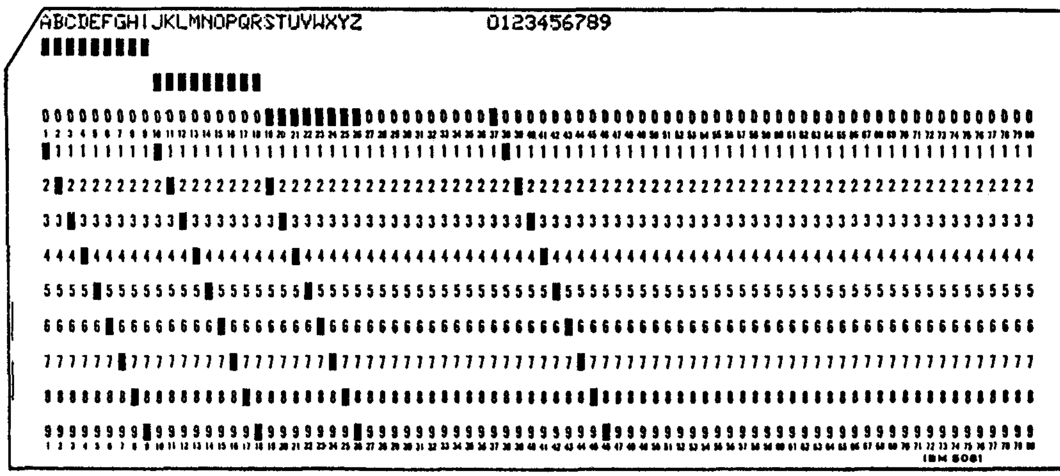

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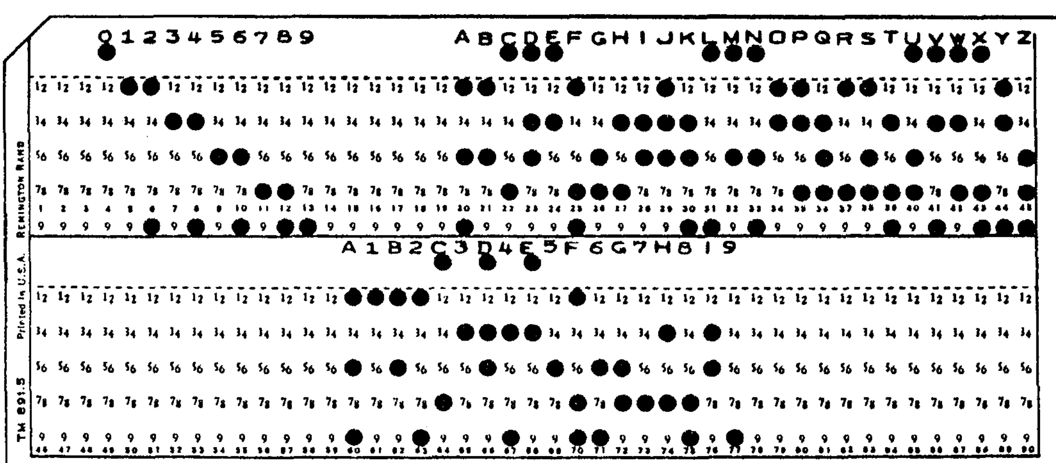

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machine industry largely held its ground, expanding again vigorously in the second half of the 1930s with the demand for government office mechanization created by the Social Security Acts of 1935, and the general increase in the size and operations of the federal government from the time of the New Deal. By the end of the decade, IBM had grown to about twelve thousand employees; it had several manufacturing plants, and large educational and research divisions at Endicott, New York. In addition, the company had marketing and manufacturing operations in most major countries (excluding the British Empire).[5]

Development of the Machinery

The most important early development of the Hollerith tabulating system occurred in connection with the tabulation of statistics for the New York Central Railroad in the mid-1890s. This commercial application had the important requirement of needing the accumulation of quantities, such as route-miles, the weight of shipments, and monetary amounts. Hollerith created for this application the multicolumn card in which numerical data could be recorded in fields of several adjacent columns (Figure 4.8).[6] To accumulate the numeric quantities Hollerith introduced a small integrating tabulator.[7] This machine, similar to that shown in Figure 4.9, used the hand-feed pin-box reading mechanism of the original census machine; selected numeric fields were added into counters of which up to four were provided.

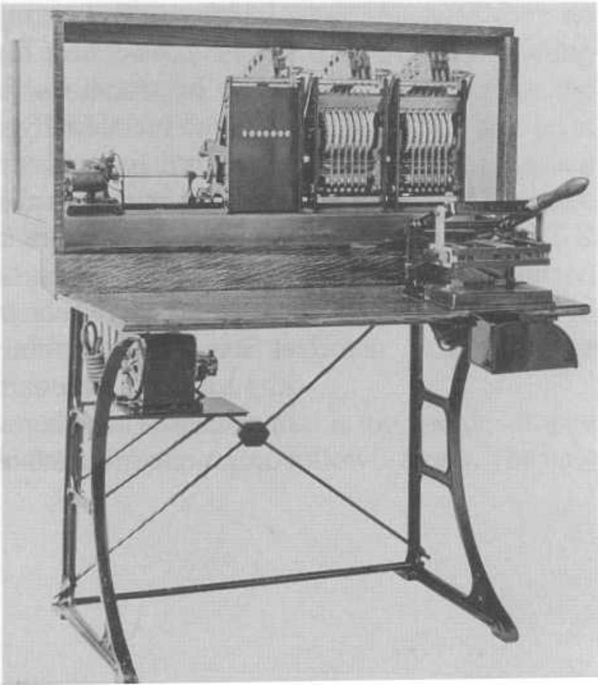


Figure 4.9. Integrating tabulator. Courtesy ICL Historical Collection.

The early 1900s, during which the Tabulating Machine Company had some success in placing machines in commercial applications, saw Hollerith and his assistant E. A. Ford make several improvements in the range and versatility of the machines. Most notably, during 1905-1907, they improved greatly the tabulator, which took on the familiar appearance of the floor-standing electrically driven machine. Figure 4.10 shows punched-card machines in use in a typical small office of the early 1900s. The new model incorporated automatic feed, which enabled it to tabulate cards at the rate of 150 per minute; this was many times the speed achievable in the hand-fed machines, and much less fatiguing. Another important improvement was the incorporation of a plugboard so that the machine could be more rapidly reconfigured to tabulate data from one card format to another; this was a great step forward on the physical rewiring that had formerly been necessary. The punched card itself went through some evolution in size and the number of columns, eventually standardized at a forty-five column, twelve-row card of dimensions 7 3/8" × 3 1/4" and corner-clipped. The automatic sorter, first introduced in 1901 for the agricultural census, was reengineered as the vertical sorter, operating at a speed of 250 cards per minute. For any card column selected by the operator the sorter would distribute cards into thirteen receiving compartments, one compartment for each of the twelve possible punching positions and a thirteenth for unpunched cards.[8] The vertical arrangement of the sorter was chosen to minimize the space occupied in a crowded office (Figure 4.10). This turned out to be an unfortunate decision, for the sorter became known as the "back-breaker," on account of the amount of stooping needed to collect the sorted cards, and it was not popular with operators.

After incorporating the Powers Accounting Machine Company in 1911, Powers and his assistant W. W. Lasker began to develop their range of machines for commercial use. The Powers machines, although functionally similar to the Hollerith machines and using the same card format, operated on different mechanical principles: in place of the electrical sensing and relays of the Hollerith equipment, the Powers machines used mechanical pin sensing and were entirely mechanical in operation, electric motors supplying nothing more than motive force. (There was some advantage in the mechanical sensing at first, as the machines were not affected by any conducting metal impurities in the cards; in the long-term, however, mechanical operation was inherently less flexible than electrical.) The new equipment included a horizontal sorter that was less tiring for

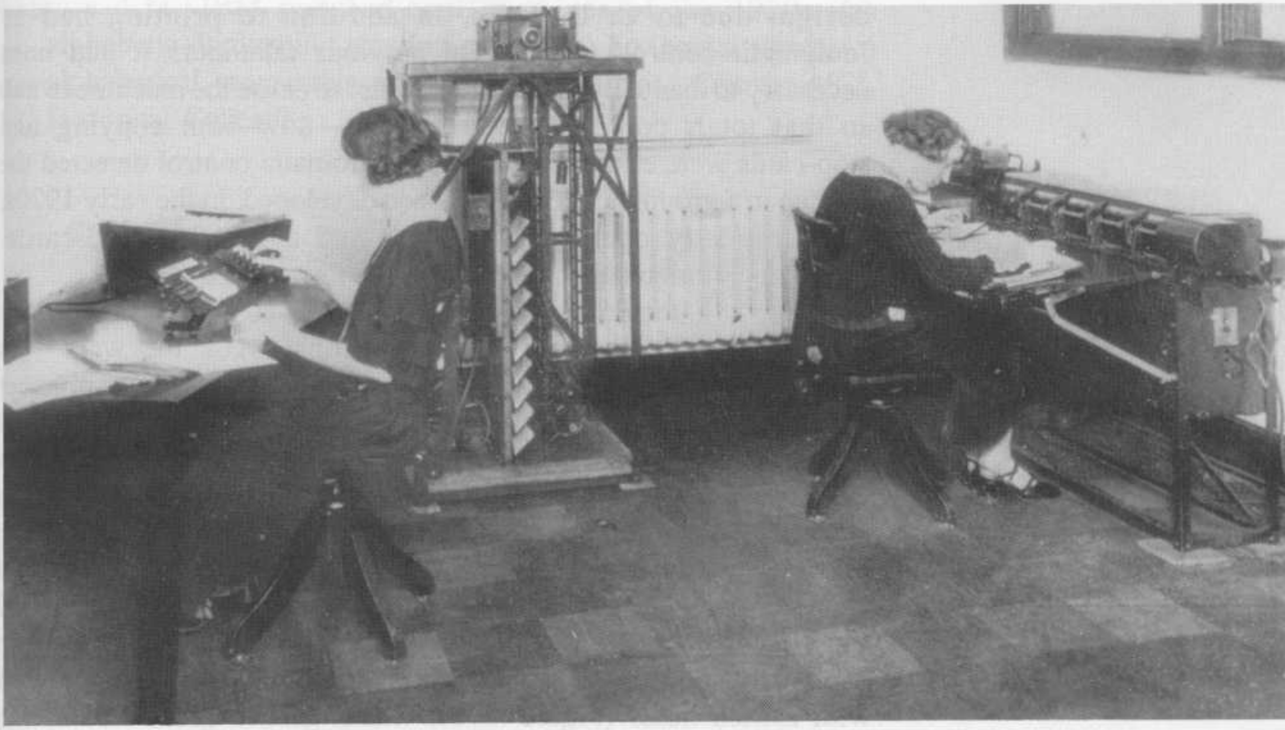


Figure 4.10. Punched-card office of the Retail Hardware Mutual Fire Insurance Company, Minneapolis, circa 1920. Note the key punch on the table at left, the vertical sorter at center rear, and the tabulator at the right of the room. Courtesy ICL Historical Collection.

machine operators than the C-T-R vertical sorter, because they no longer had to stoop to remove the cards. The Powers printing tabulator was a far superior device to that offered by C-T-R. First, the machine had a printing head that enabled it to list cards and print totals. And second, it was fitted with a "connection-box" that enabled it to be reconfigured for a new application in a matter of seconds, compared with the much longer time needed to replug the C-T-R machine. The first card punch (the so-called slide-punch) produced by Powers was less satisfactory, and it was quickly replaced in 1916 by an electrically driven key punch of a similar pattern to the hand-operated Hollerith punch.

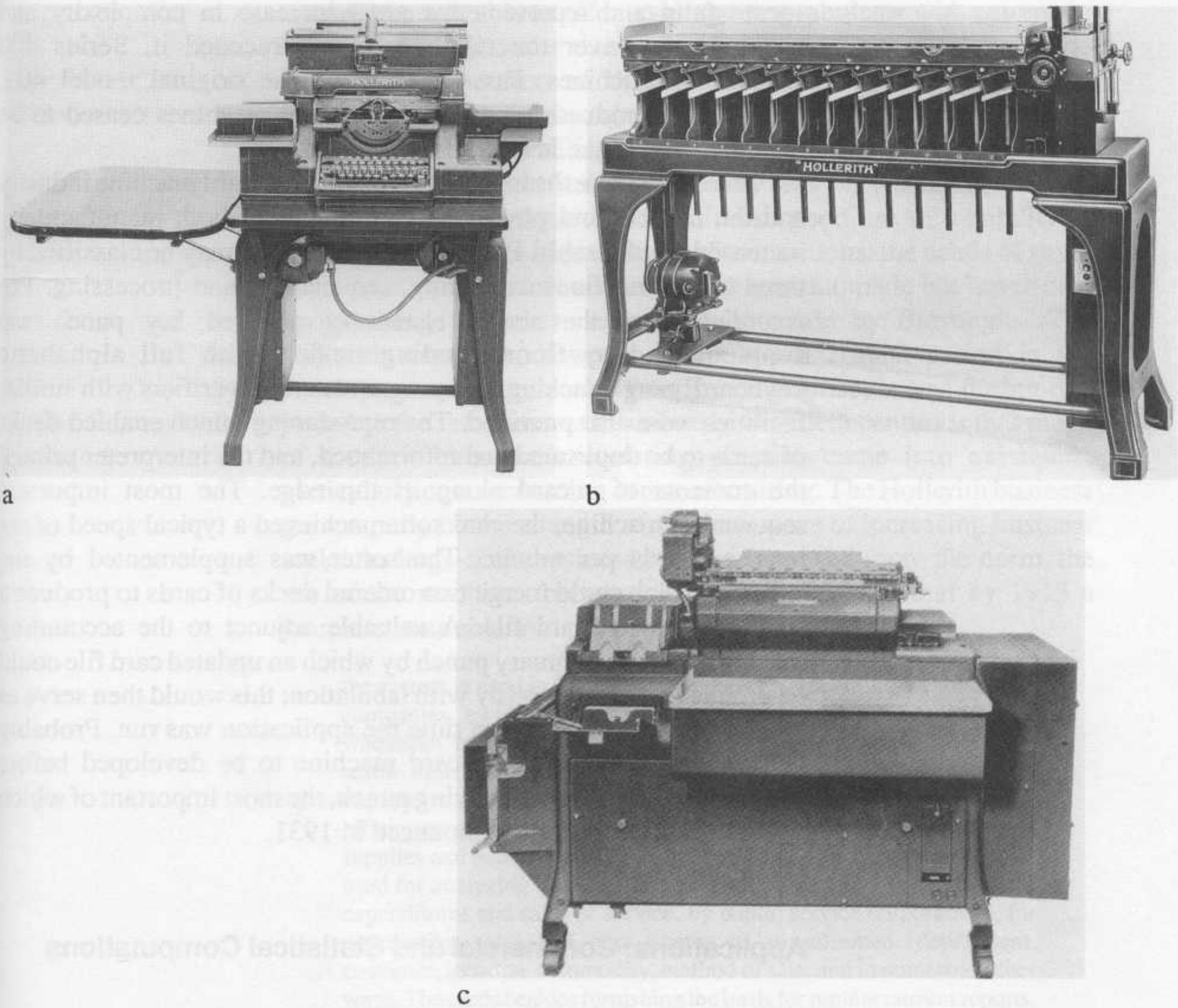
By 1919, C-T-R was able to announce that it too had developed a printing tabulator, which was marketed the following year. The new design, due to C. D. Lake, in addition to printing had an "automatic-control" device. On previous tabulators it had been necessary to manually insert "stop-cards" to cause the machine to halt so that totals could be copied down—now both copying and stop-cards were eliminated, because automatic control detected the change in a group number. C-T-R also developed, in the early 1920s, an electrically operated keypunch and a four-hundred-cards-per-minute horizontal sorter that rivaled those of Powers.

In its turn, the Powers organization achieved what was probably the single most important development between the wars—the introduction of alphabetic equipment in 1924. Letters of the alphabet were encoded in a single column of the card by means of a special code, the 45-column cards being otherwise identical to those used on the numerical equipment. Both an alphabetic tabulator and an alphabetic keypunch were provided. The introduction of alphabetic equipment opened up entirely new areas of commercial application that had not been possible with the numerical-only machines. IBM subsequently brought out its own, rather more flexible, alphabetic equipment. In 1928, IBM introduced the familiar 80-column card with slotted holes (Figure 4.8b), which gave a great increase in capacity over the 45-column card. Remington Rand followed suit in 1930 with a 90-column card, in which two characters were punched in each of 45 columns (Figure 4.8c).

This pattern of development—each of the two manufacturers bettering the offerings of the other—is one that, in broad terms at least, characterized the development of punched-card machinery between the two world wars. The development of punched-card machines illustrates, in microcosm, the accelerating trends in automatic control and operation that swept across the developed world during that period. Over the years hundreds of improvements were made by each manufacturer to its products and equally large numbers of patents were taken out. Of the many improvements only a handful were really fundamental, but the cumulative effect of hundreds of minor improvements was to transform the machines. Increasingly, the machines required less and less operator intervention and became more sophisticated in their operation. For example, the introduction of "major-minor" automatic control enabled two levels of subtotalling to be performed automatically, and eventually three levels.[9]

In the early 1930s, IBM introduced a range of 80-column machines that were a high point in the interwar development of

Figure 4.11. IBM punched-card machines of the 1930s: (a) alphabetic duplicating printing punch, (b) horizontal sorter, (c) alphabetical accounting machine (Tupe 405). Courtesy ICL Historical Collection.



punched-card machinery (Figure 4.11). The leading machine of the series was the model 405 alphabetic electric accounting machine.[10] The new accounting machine inherited all the improvements of the previous decade—three levels of automatic control were provided, a replaceable plugboard enabled an application to be changed in seconds, paper feed mechanisms enabled standard sized continuous stationery to be used for the print out, and full subtraction facilities were provided; cards could be totalled at the rate of 150 per minute, or listed at a speed of 75 cards per minute. The 405 was a very flexible machine that required a significant training period to learn to use successfully and represented a great increase in complexity and sophistication over the tabulators that preceded it. Series 400 accounting machines, based closely on the original model 405, remained in production until punched-card machines ceased to be manufactured in the late-1960s.

The 1930s were the heyday of the punched-card machine industry and the number and power of the products of both manufacturers increased considerably. Punched-card machines may be classified by three broad functions: recording, sequencing, and processing. For recording data, the simple electrically powered key punch was supplemented by floor standing models with full alphabetic keyboard, gang punching, and program control; verifiers with similar facilities were also provided. The reproducing punch enabled decks of cards to be duplicated and reformatted, and the interpreter printed the contents of a card along its top edge. The most important sequencing machine, the card sorter, achieved a typical speed of six hundred cards per minute. The sorter was supplemented by the collator, which could merge two ordered decks of cards to produce a single-sequenced card file. A valuable adjunct to the accounting machine was the summary punch by which an updated card file could be produced simultaneously with tabulation; this would then serve as the new master file the next time the application was run. Probably the most complex punched-card machine to be developed before World War II was the multiplying punch, the most important of which was the IBM model 601, announced in 1931.

Applications: Commercial and Statistical Computations

The earliest uses of punched-card machines were statistical; it was not until the Tabulating Machine Company's second decade that accounting applications began to dominate. This trend accelerated markedly with the appearance of printing tabulators that had automatic control in the early 1920s and the later appearance of alphabetic equipment. Accounting machines were not designed with mathematical computation in mind, but their use in this context was an important link between the prewar world of mechanical computation and the postwar world of electronic computers.

Although Hollerith made a little progress in the commercial field during the early years of the Tabulating Machine Company, it was not until he was able to offer an integrating tabulator with automatic feed and vertical sorter that major accounting operations could be undertaken. The first of these was for the Pennsylvania Steel Company in 1904 and the second was a sales analysis application for the Marshall Field retailing organization. Punched-card machinery was expensive to rent and consequently was only used, at first, by very large organizations that could make good use of its ability to make short work of a large volume of transactions; the needs of small businesses could be met adequately by less automatic but lower-cost bookkeeping machines, such as those made by Burroughs. The Hollerith machines, however, arrived at a critical period in the development of large-scale American enterprise; it was during this period in the late nineteenth and early twentieth centuries that much of modern business accounting practice came into existence, particularly cost accounting in manufacturing. The Hollerith business grew rapidly on the strength of this new wave of increasing business scale. As large-scale business became more and more the norm, the use of the machines became quite widespread, so that by 1913 a journalist was able to report

> the system is used in factories of all sorts, in steel mills, by insurance companies, by electric light and traction and telephone companies, by wholesale merchandise establishments and department stores, by textile mills, automobile companies, numerous railroads, municipalities and state governments. It is used for compiling labor costs, efficiency records, distribution of sales, internal requisitions for supplies and materials, production statistics, day and piece work. It is used for analyzing risks in life, fire and casualty insurance, for plant expenditures and sales of service, by public service corporations, for distributing sales and cost figures as to salesmen, department, customer, location, commodity, method of sale, and in numerous other ways. The cards besides furnishing the basis for regular current reports, provide also for all special reports and make it possible to obtain them in a mere fraction of the time otherwise required.[11]

Sales analysis, first undertaken for Marshall Field in about 1907, was a very common commercial application, and it illustrates well the use to which punched-card machines were put. Sales transactions were recorded onto cards, different fields recording the salesman number, the value of the transaction, the value of the commission, the product code, and so on. (Fig. 4.8a shows a typical early sales card.) To total up the commissions for each individual salesman during an accounting period, for example, the cards would be sorted by salesman number, which would put all the transactions for each salesman into juxtaposition. Blank stop-cards would then be inserted to separate the cards for each salesman from the next. Finally, the cards would be run through the tabulator; as each stop-card was encountered the tabulator would halt, so that the total commission for the salesperson could be copied into a ledger for subsequent payment.[12] The same sales cards could also be used to provide other analyses. For example, to examine stock movement during a period, the total sales of each product would be required. This could be quickly obtained by sorting the sales cards into product code order and performing another tabulation. A great point was made by tabulating machine salesman of the "unit record" principle: that a single record could serve a variety of purposes by the simple process of sorting and tabulation.

The demands of commercial applications were a prime stimulus to the production of new tabulating equipment. For example, the introduction of alphabetic equipment was a direct response to the need for names and addresses and alphabetic descriptions on tabulator listings; and the provision of several levels of automatic control enabled very sophisticated customer statements and management reports to be produced. Accounting machines only added and subtracted, so that utility companies, for example, who charged customers on unit-cost-times-quantity basis had to perform the necessary multiplication prior to the punching operation. The multiplying punch introduced in the early 1930s was designed to satisfy this need.[13]

Just as the needs of commerce were a spur to the development of the punched-card machine industry, the technology also helped to shape the organization of business. Thus, the highly centralized accounting systems of industry were very much geared to what was technically achievable with the commercially available machines, and a generation of accountants between the two world wars grew up on a diet of the standard textbooks on mechanized accounting. When computers became available in the 1950s and 1960s, they tended to be used at first as glorified electric accounting machines and were simply absorbed into old-fashioned accounting systems. It took a new generation of accountants, and much trauma, to exploit the potential of the computer, particularly its capability for dealing with transactions in real time.

Applications : Scientific Computation

In the 1930s the two principal means of performing digital computation were using desk calculators or punched-card machines. Though the use of desk machines was very widespread (see Chapter 1), there existed just a few centers using punched-card machines. In volume terms, the number of punched-card machines used for digital computation before World War II was quite insignificant, but they were important in creating an awareness of their computational possibilities within the scientific establishment and within the punched-card industry itself.

The first person to make use of punched-card machines in scientific computation was L. J. Comrie, superintendent of the Nautical Almanac Office, Greenwich, England. Comrie was, in principle, opposed to the construction of special-purpose computing equipment and had already established his reputation by adapting commercial accounting machines to scientific ends. Comrie first used punched-card machines in connection with Brown's Tables of the Motion of the Moon in 1929, which he described in a classic paper published in 1932. Comrie subsequently resigned from the Nautical Almanac Office to form his own company, Scientific Computing Services (SCS), in 1937. SCS became a leading center for digital computing and, before the war, it was the only British computing service to make use of punched-card machines. It is perhaps indicative of the scale of computational activity of the day that SCS could not justify the cost of acquiring machines but mainly used the bureau service of the British Tabulating Machine Company.

In the United States, astronomical computation also provided a motive for using punched-card machines for digital computation. Wallace J. Eckert (1911-1976), an astronomer at Columbia University, learned of Comrie's activities in England and began in 1933 to do similar work using the punched-card machines housed in the Columbia University Statistical Bureau in New York.[14]

In 1934, Eckert became director of the Scientific Computing Bureau at Columbia, which was the first American center for punched-card computation, using machines donated by IBM; in 1937, the laboratory was renamed the Thomas J. Watson Astronomical Computing Bureau. The computing bureau accepted a wide range of computational tasks, such as harmonic analysis, the integration of differential equations, and the construction of astronomical tables.

Table 4.1. Punched-card machine tabulation of $y = x^2 + 2x + 1$

Argument x	Function y	First difference	Second difference
0.00	1.00		
		0.21	
0.10	1.21		0.02
		0.23	
0.20	1.44		0.02
		0.25	
0.30	1.69		0.02
		0.27	
.	.	.	.
.	.	.	.
.	.	.	.
etc.			

One of the most elegant and simple of Eckert's techniques, the tabulation of a function by the method of differences, illustrates punched-card computing nicely. Suppose it was required to tabulate the function $y = x^2+2x+1$ for $x=0$ to 1 in steps of 0.10 (Table 4.1). The process would begin by recording the constant second difference on a total of ten cards, using the gang punch and placing a card containing the top value of the first difference column at the front; i.e., the deck would contain the value 0.21, 0.02, 0.02, 0.02. . . . The cards would then be run through the tabulator and successive totals recorded on cards using the summary punch. The top value of the function column would then be placed at the front of the new card deck, which would now contain the values 1.00, 0.21, 0.23, 0.25. . . . Finally, a last run through the tabulator of this card deck would produce a listing (and a card deck if required) containing the values 1.00, 1.21, 1.44, 1.69. . . , the required table. In practice, the process was a little more complicated than this.

Some of Eckert's more complex calculations—notably the integration of differential equations—required the use of a multiplier, a tabulator, and a summary punch acting in concert. Eckert commissioned a "calculation control switch" that enabled a sequence of arithmetic operations to be performed during a single card passage; this was one of the earliest examples of automatic sequence control. Eckert later developed these ideas in the IBM Pluggable Sequence Relay Calculator (see Chapter 6) and the Selective Sequence Electronic Calculator (Chapter 7).

Postwar Development

After the many technical developments of the 1930s, the war years saw relatively little advance in punched-card machine design due to the supervention of other wartime research priorities. The manufacture and use of the machines, however, increased considerably. IBM, for example, emerged from the war with nearly twice the employees it had when the war began.

The two most important wartime developments were the application of electronics and the development of sequence-controlled calculators. A prototype electronic multiplier was available within IBM by the end of 1942, although it was not until 1946 that it became commercially available as the model 603; operating at one hundred cards per minute, it was about ten times faster than the electromechanical 601. During the last year of the war, IBM developed the Pluggable Sequence Relay Calculator. This machine, which was capable of performing a sequence of up to fifty arithmetic steps, was specified by W. J. Eckert and designed and built by a team led by C. D. Lake and B. M. Durfee.

In 1948 these two developments were brought together in the IBM 604 electronic calculating punch—a machine with 1,400 electronic tubes and a capacity of sixty program steps. More than 5,000 of these calculators were sold during the next ten years. The other punched-card machine manufacturers quickly followed IBM's lead by introducing electronic multipliers and calculating punches in the next few years. The IBM 604 was the main computing element in a very important development, the Card-Programmed electronic Calculator (CPC). The CPC was a popular transition machine that sold in hundreds until reliable, moderately priced, stored-program computers became available in the mid-1950s.

The introduction of electronics into punched-card machines was, in a phrase of the period, "evolutionary not revolutionary"; that is to say, the functional characteristics remained unchanged and the new technology merely enhanced the speed and reliability of the machines. It is obvious in retrospect that by the early 1950s punched-card machines were a declining technology, that they would eventually be superceded by electronic computers. The speed with which this happened, however, is often exaggerated. Electronic computers were for several years expensive and unreliable alternatives to traditional tabulating equipment, and could only be justified by the largest and most prestigious data processing users; for prudent business people, tried and trusted electronic accounting machines were generally a more sensible choice. During the 1950s some very competitive new punched-card machines were introduced that occupied "that ill-defined boundary which divides computers from calculators." For example, in 1958 IBM announced its model 628 calculating punch, which used second generation transistor electronics, had a small magnetic core memory, and could be plugged with up to 160 program steps. Another second generation calculating tabulator, the Univac 1004 (Figure 4.12), was introduced by Sperry Rand in about 1962, and many hundred were sold in the United States and Europe. Even as late as 1959 there were less than four thousand

Figure 4.12. The Univac 1004 calculator, also sold in the United Kingdom and Europe as the ICT 1004, shown here, by International Computers and Tabulators (ICT, the descendant of the British Tabulating Company). Courtesy ICL Historical Collection.

computers in the United States, compared with several thousand punched-card machine installations. It was probably not until the launching of the IBM 1401 in 1959, outstandingly the most successful early data processing computer, that this began to change.

By the late 1960s traditional punched-card machines had effectively gone out of production, although punched cards themselves continued to be the dominant input-output medium for electronic computers. IBM flirted briefly with a new 96-column card in 1969 for its small System/3 range of computers, and included an off-line sorting machine, but it was not a commercial success. During the 1970s even this vestigial use of punched cards declined with the increasing use of direct data entry on visual display units. By the late 1980s punched cards had all but vanished.

Notes

1. Color-nativity is the racial type and country of birth. Tenure equals farm or home ownership. The overt interest of the Bureau of the Census in statistics of race is sociologically interesting, but beyond the remit of this chapter.

2. The relay circuits we now recognize as simple AND and OR logic functions, but such a formalism did not exist until the late 1930s.

3. G. Austrian, *Herman Hollerith: Forgotten Giant of Information Processing* (New York: Columbia University Press, 1982), 72.

4. Although BTM derived the full benefit of IBM's research and development, it was required to pay a 25 percent royalty for the privilege. This onerous royalty rate frustrated the growth of BTM; and because it also lacked Watson's charismatic leadership, it never prospered to anything like the extent of IBM in America. It never became more than about one-twentieth the size of IBM, in spite of having a sales area of one-third of the developed world.

5. Comparative data for IBM and the Remington Rand Tabulating Machine Division are hard to come by. Although Remington Rand had overall revenues comparable with IBM, the bulk of its

revenues were derived from typewriter sales and other office products. According to contemporary sources, IBM had about an 80 percent share of the American tabulating machine market and Remington Rand about 20 percent.

6. Apart from the population census, where the old form of card persisted, the multicolumn format of cards was universally adopted; Figure 4.8a shows an example dating from shortly before World War I.

7. Hollerith had in fact experimented with an earlier integrating tabulator for the Office of the Surgeon General in 1899 and for the Agricultural Census in 1893. All types were based on a Leibniz stepped-wheel adding mechanism (see Chapter 1).

8. Because the card sorter only operated on a single column, to sort a field of *n* digits, cards had to be passed through the sorter *n* times, starting with the most significant digit. An analogous sorting technique in computer programming is known as the bucket or radix sort. See D. E. Knuth, *The Art of Computer Programming*, vol. 3 (1973), 382-84.

9. It is interesting that a vestige of this old accounting machine control mechanism remains in the RPRG programming language, which in fact evolved as a simulator of punched-card accounting machinery.

10. Gradually the term *electric accounting machine* or *EAM* had come to be preferred to *tabulator*, reflecting the shifting domain of application.

11. S. G. Koon, "Hollerith Tabulating Machinery in the Business Office," *Machinery* 20(1913):25.

12. The insertion of stop-cards and the copying down of totals were time-consuming operations that were entirely eliminated in the printing tabulators with automatic control of the 1920s.

13. Before the arrival of the multiplying punch, an ingenious technique known as "progressive digiting" enabled cumulative products to be computed using only a tabulator and a sorter; this

method was devised in the 1920s to compute ton-mile statistics for railroad companies but largely fell into disuse when multiplying punches became available. See J. C. McPherson's introduction to the Charles Babbage Institute Reprint Series edition of W. J. Eckert's *Punched Card Methods in Scientific Computation* (1940).

14. The Columbia Statistical Bureau was one of several statistical units, established in American universities and government departments in the 1920s and 1930s, that used punched-card machines for large-scale statistical research. Another well-known center was at Iowa State College. During World War II many more statistical laboratories came into existence for operations research and statistical investigations.

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