Digitizing Measurement: Automating Scientific Table Making.*

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Abstract. Wallace J. Eckert, Columbia University astronomy professor and IBM researcher, is best known for his pioneering work with calculating machines in the mid-twentieth century in celestial mechanics. However, Eckert also did extensive work with scientific tables. In the 1930s he developed techniques with punch card machines to reduce data for star catalogues, this also made the data machine readable and sortable. This work sped up and allowed the extension of important catalogues of stars. In 1940 Eckert became director of the Naval Almanac Office of the United States. In this position he automated the calculations used in the production of the Nautical Almanac's navigation tables using punched card machines. In the process proof-reading and typesetting were also automated. At the same time Eckert organized the publication of the new Air Almanac for airplane navigation. After joining IBM in 1945 Eckert directed work to create an automatic measuring engine of star positions on photographic plates, this was completed in the early 1950s. With this work Eckert began the digitization and automation of astronomical data that has subsequently allowed every greater quantities of data to be accumulated and analyzed. My paper will draw from published accounts of Eckert's work, supplemented by archival material, to summarize this work, its character and impact.

Keywords: history of computing, punch cards, scientific tables, automating measurement, digital measurement

Wallace J. Eckert (1902-1971) is best known for his pioneering work on calculating machines and early computers in the 1930s and 40s and his life long work improving lunar theory. However, he also did extensive work on scientific table making, including many innovations with calculating machines.

The connection between calculating machines and table making goes back well before Eckert's work. Charles Babbage was inspired to begin his invention

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of ever more complicated calculating machines by the tedious work of preparing astronomical tables, in the 1820s. In his quest to remove human error Babbage even planned that his difference engine would form molds for printing plates of its results.[1][2] Despite such ambitious plans Babbage's work failed to produce much change in the way tables were prepared.

It was not until the 20th century that calculating machines would significantly impact the making of astronomical tables. One of the most noted developments is the work of L. J. Comrie (1893-1950). Comrie while Deputy Superintendent of Her Majesty's Naval Almanac Office reformed the means of calculating the tables produced by the office, including installing desktop mechanical calculating machines.[3]

Comrie is best remembered for a project begun in 1928 to calculate the motion of the moon for astronomical and navigational tables, based on the tables of E. W. Brown (1866-1938), using Hollerith punched card machines. These machines were capable of automatically adding and sorting numbers punched into cards. The project involved twenty million holes punched in half a million cards. These cards contained numerical values of the over 1400 harmonic functions that built up Brown's solution at representative intervals. By feeding properly organized stacks of these cards into the the machine, the position of the moon at regular intervals could be found.[4] Comrie estimated that the methods: "Eliminated much fatigue, increased tenfold the speed with which results can be obtained, and reduced the cost to only a quarter of its former amount."[4] In any case Comrie's work represents a significant step forward in the automation of the calculations used in astronomical tables.

E. W. Brown not only provided the theory on which Comrie's work was based. Brown also visited Comrie in England in 1928 and communicated Comrie's work to a North American audience at the annual meeting of the American Astronomical Society that year. [5][6] Perhaps more importantly E. W. Brown's student at the time was Wallace J. Eckert. It is not clear if Eckert learned of Comrie's work through Brown, but Eckert explicitly acknowledged Comrie's influence in his later work.[7]

Brown shows a sustained interest in calculating machines and their application to astronomy that has been little noted. In 1912 he published a paper in the Monthly Notices of the Royal Astronomical Society entitled "On a device for Facilitating Harmonic Analysis and Synthesis." It suggests a technique for solving harmonic equations, like Brown's equation for the motion of the moon, not unlike Comries approach with Hollerith machines, but replacing punched cards and machines with tapes of printed numbers and a human operating a desktop calculator.[8] It is not clear if Brown's work had any influence on Comrie but the common interest suggests the general interest in astronomy in attempts to automate calculation, in the early 20th century.

Becoming an instructor in astronomy at Columbia University also influenced Eckert in his use of calculating machines. Here he came into contact with the statistical laboratory of Ben Wood a professor of education.[9] This laboratory used IBM (Hollerith) punched card machines to do calculations. Eckert used these machines to do numerical integrations on the orbits of asteroids.[10] In 1934 Eckert obtained his own set of IBM machines and this laboratory would become the Thomas J. Watson Astronomical Computing Bureau in 1937, named after the then president of IBM.[9]

The Columbia astronomical laboratory continued Eckert's work calculating asteroid orbits. It was also used by Eckert in collaboration with Brown to verify Brown's lunar tables.[11] The laboratory also undertook three projects involving the partial automation of table making work.

The Yale Zone Catalogue project had already begun, when the resources of Columbia's punched card laboratory were applied to it. The project sought to re-observe the relative positions of all the stars in the A. G. Catalogue, recorded around 1900. Whereas the A. G. Catalogue used direct measurement the Yale project involved the use of photographic plates. Therefore it was necessary to convert the spherical coordinates of normal observation and existing tables into the rectangular measurement of position of each photographic plates. Also, in order to compare the position of the star to the earlier records precession had to be calculated and accounted for. It was these calculations that were done via punched card machine. Eckert estimated that half of the computations for the project were done via punched card and that a 50 percent savings in cost were obtained on calculations done in that way. The results were also printed by the tabulator rather than hand copied from the machine.[12]

The limitations of the punched card machines of the era made the application more complicated than it might sound. For example, the calculation of rectangular coordinates was done according to the following expression:

$$X = K(\tan \Delta\alpha)/(\tan \delta' \sec \Delta\alpha \sin \delta + \cos \delta) \quad (1)$$

$$Y = K(\tan \delta' \sec \Delta\alpha \cos \delta - \sin \delta)/(\tan \delta' \sec \Delta\alpha \sin \delta + \cos \delta) \quad (2)$$

The machines could not evaluate trigonometric functions, so tables (often in punched card form) and hand interpolation were used to find the values for trigonometric functions. Similarly division was achieved by multiplication of reciprocals found by reference to a table in punched card form.[12]

Another astronomical table project aided by the Columbia machines was the stellar photometry project of Columbia University's Rutherford Observatory. The project measured the relative brightness of thousands of stars on photographic plates using electric photometry. The stars examined had been previously listed in star catalogues. In addition to the conversion of coordinates from the spherical coordinates of the night sky to the rectangular coordinates of the plate, the punched card machines were used to calculate the correction of the measured brightness for the background of the individual plates. This involved a least squares fit of the correction curve for each plate. In Eckert's opinion the use of the machines made the extended version of the project, measuring as many as 150 000 stars, possible. Again the printing feature of the tabulator was used to print the final results of the measurement and calculation.[12]

One final astronomical table project undertaken by Eckert at Columbia in the 1930s was a punched card table of data from the Boss General Catalogue.

This project involved putting data from the Boss Catalogue of 33 342 stars onto punched cards along with calculation of some other properties to be punched on the cards. Rather than using the punched cards primarily for calculation of derived properties of the individual stars the primary purpose of the transcription was to allow statistical study of the stars and their properties, operations for which the IBM accounting machines were well suited. Another advantage was the ease of mechanically copying sets of cards. The advantages for computation of additional quantities along with the ease of printing portions were other considerations.[13] Eckert and the Computing Bureau made duplicates available for the cost of materials and labour. According to Eckert the card version of the Boss Catalogue was still in use as late as 1967.[14] Copies of data on punched cards from the other astronomical tables used in calculations at the lab were similarly available from the computing bureau.[12]

Eckert's biggest role in automating table making came in 1940 when he became Director of the Nautical Almanac Office of the United States. Here he converted the calculation and preparation of tables to the use of punched card machines.[9]

The most significant table that Eckert produced during his time at the Almanac Office was a new Air Almanac. The standard work of the Office, the Nautical Almanac, consisted of daily positions of the various celestial bodies for the purpose of navigation and astronomy. The Air Almanac includes similar values but at shorter time intervals allowing an air pilot to quickly calculate his position. The Second World War made this Almanac of critical importance.[9] In order to insure the highest accuracy Eckert developed a means of proof reading that used punched cards.

The final values to be printed existed on punched card as the result of calculations. The values on the printer's proofs of the tables would be punched onto cards by a member of the clerical staff. The two sets of cards would be mechanically compared. This technique proved to be fast, effective and required less skill. In later editions of the Air Almanac the output of the machine was printed directly from the punched cards. This was achieved at first by ad hoc modification of a tabulator to print the results in a smaller more legible font required for the Almanac. The printing plates for this were prepared by a photographic process from these print outs. In 1945 IBM delivered to the Office a card operated typewriter making the production of high quality printed tables from punched card data relatively straightforward.[15] As result of these techniques Eckert could boast that no error had ever been found in the Air Almanac.[16]

The accuracy provided by the machine calculation of the content created motivation for these measures to ensure accuracy. As Eckert later described it: "It was too troublesome to send perfect copy to a printer and have it come back with an error a page and then go through it all again and have it come back with an error in one hundred and so on."[17] The increased accuracy of machine calculation made the error involved in traditional type setting and proof reading stand out and become unacceptable.

In 1945 Eckert left the Almanac Office for a position as head of the Pure Science Department at IBM. Here he helped develop one of the first general purpose automatic electronic computers. He also continued working on the automation of astronomical tables with a project to build an automatic measuring engine for star positions from photographs. The machine could find a star from approximate coordinates and automatically measure the star's position with great precision. The position thus determined would be more precise than a human operator could achieve. Also, the measurement was outputted on a punched card making machine calculation quick and straightforward.[18]

Eckert begins his description of the automatic measuring device by noting the intense amount of "hard labor", for the astronomer, associated with the production of star catalogs. He suggested: "The catalogs of the future will require his scientific insight but for his routine labor will be substituted the technological developments of our age."[18] Eckert viewed his automatic measuring engine as completing the mechanization of tables begun with machine calculation of values.

At least for Eckert the automation projects he undertook followed naturally. Firstly as an elimination of drudgery. Also as error was removed form one part of the process it became intolerable in others. Finally as calculation, printing and distribution became automated having the data of observation in a machine readable format became more attractive.

The automation of astronomical data collection and analysis has continued to this day. This has resulted in survey projects, such as the Sloan Digital Sky Survey, that has measured various aspects of millions of objects in the sky and produce terabytes (10^{12} bytes) of data.[19] Eckert's work marks some of the first steps along this path of digital measurement and data management in astronomy.

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