REVIEWS

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When Computers Were Human. By David Alan Grier. Princeton University Press, Princeton, NJ, 2005, viii + 411 pp., ISBN 0-691-09157-9, $35.00.

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As I was reading the wonderful book under review, I was reminded of another work on the history of computers that I read some thirty years ago. Ostensibly the earlier book, *The Computer from Pascal to von Neumann* [**2**] (henceforth *CPvN*), is concerned with a similar topic in roughly the same period. Its author, Herman H. Goldstine, informs us in the preface that his emphasis is on ideas and people instead of equipment, which would seem to parallel Grier's *When Computers Were Human* (henceforth *WCWH*). So I reread *CPvN* in light of *WCWH* and benefited appreciably from a second exposure. This review will concentrate on *WCWH*, but will initially use *CPvN* for what I hope are illustrative and illuminating comparisons.

While you cannot always tell a book from its cover, the ones adorning these two works are telling. *CPvN* displays three people (John von Neumann and J. Robert Oppenheimer pictured in front of the Institute of Advanced Studies computer, and J. M. Jacquard at an automatic loom), but it also includes photos of the Mark I computer, the difference engines of Babbage and Scheutz, and numerous tables of binary digits. So its cover tells us that the contents will be a balance between man and machine. By comparison, the *WCWH* cover features only one photo—a young woman, perhaps during the 1930s, judging from her dress, inputting data into a machine that appears to be a tabulator. Its cover thus tells us that the overarching emphasis will be on individuals, notably women. However, whereas both books concentrate on people, the main characters in their books are essentially disjoint and occupy different rungs on the mathematics/computer science ladder. *CPvN* features patricians like the great von Neumann and J. Presper Eckert; *WCWH* highlights plebeians like the anonymous woman on the cover and Wallace Eckert (an astronomer who became an important part of the Columbia University Astronomical Computing Bureau).

There is also an important difference between the authors. Herman H. Goldstine (1913–2004) was one of the primary developers of modern computers. Because of this personal involvement, he went to great lengths in his preface to minimize the effects of personal bias. David Grier, on the other hand, was still in high school when the Goldstine book appeared, so he was too young to have participated in any of those developments. He might appear, on the surface, to be a disinterested observer, but he is no rank amateur in either computing or its history, having worked in the computer industry before moving into academia and serving as Editor in Chief of the *IEEE Annals of the History of Computing*, where much of his writing has appeared over the past eight years. He has also delivered invited addresses on the subject at special sessions on the history of mathematics at two joint meetings and has published two related papers in this MONTHLY.

Yet Grier too has a personal stake, one that engages the reader from the outset. (The clever title adds to the allure of the book.) In Grier's introduction, titled "A Grandmother's Secret Life," he reveals that his attraction to the topic was sparked by an off-hand comment by his maternal grandmother: "You know, I took calculus in college." And indeed, after performing a historian's detective work, the grandson located a photo of her in a calculus class at the University of Michigan in 1921. Although she never put her mathematics degree to use, the incident caused Grier to wonder about the other five female mathematics majors who graduated that year and put their degrees to work by performing arithmetic calculations for scientific research. This source of inspiration for Grier explains why his book is so different from Goldstine's and suggests the important niche it fills in the literature.

It is germane to point out that the name Goldstine does appear in *WCWH*, but it is Herman's first wife Adele and not her illustrious husband. Like the motivating grandmother, Adele Goldstine (1920–1964) possessed a degree in mathematics from Hunter College and a master's degree from Michigan. The purpose of stating this fact is to point out that *WCWH* is concerned primarily with contributions made by a talented, hard-working underclass of individuals who were women as well as "African Americans, Jews, the Irish, the handicapped, and the merely poor" (p. 276).

WCWH is meticulously documented, with over twelve hundred footnotes. These references are formatted as endnotes, so they do not interrupt continuity for readers uninterested in such details, yet they supply the historian with needed evidence. Photos abound too; they help humanize a subject already abundantly humanized in text. There are very few typos, but one that I found amusing is a note at the end of the index entry for Galton Laboratory that was probably meant for the typesetter and not the reader.

I enjoyed *WCWH* very much and learned a lot from it; at times it reads like a novel that one cannot put down. Yet when I studied it, I often found myself lost in a morass of names and interconnecting events. To his credit, David Grier must have anticipated such a problem, because he supplies an appendix with brief descriptions of recurring characters, institutions, and concepts. But I found this aid not entirely effective. Hence, the rest of this review provides an overview of the subject for the typically time-challenged mathematician interested only in reading a review and supplies a prospective reader with an outline of the contents to help keep sight of the forest in spite of the density of the trees. The accompanying table presents the outline; the first column describes the events, the second the leading characters, and the third the women who either headed up a project or played a prominent role. (Question to reader: What percentage of names do you recognize in the second versus the third column?)

Now we examine *WCWH* and summarize its contents, which overall provide a structure for understanding what is now known as big science—projects involving labor, capital, and machinery for solving large problems of scientific research. Part 1 deals with the division of labor, beginning with Edmund Halley's solitary attempt to predict the return of his eponymous comet in 1682 but quickly moving to A.-C. Clairaut's approach to its return in 1758. The essential difference is that Clairaut recognized that the long astronomical computations could be split into pieces, so he divided them up among two assistants, the well-known astronomer Joseph Lalande and the virtually unknown astronomer Nicole-Reine Lepaute. The next advance on this front took place in England when Nevil Maskelyne formed a staff of five human computers in 1765 to work on celestial tables (called ephemerides) for the Nautical Almanac. (Officially called the Royal Nautical Almanac, this office prepared annual volumes of navigation and astronomical tables. An American version was created in the next century.) Back on the continent, after the French revolution, Gaspard de Prony formed a staff of nearly a hundred human computers to help with the standardization of weights

ASTRONOMY 1685–1880		
Halley's comet	Alexis-Claude Clairaut Nevil Maskelyne	Nicole-Reine Lepaute
Metric system	Gaspard De Prony	
Greenwich Observatory	George Airy	
American Nautical Almanac	Charles H. Davis Benjamin Peirce	Maria Mitchell
STATISTICS 1880–1930		
Biometrics; ballistics	Karl Pearson	
Aberdeen	Oswald Veblen	
Ballistics	Forest Moulton	Elizabeth Webb Wilson
1920s machines		
Department of Agriculture	Raymond Pearl	
University of Iowa	George Snedecor	Mary Clem
Bell Labs	Thornton Fry	Clara Froelich
COMPUTERS 1930–1964		
MTAC	R. C. Archibald	
MTP	Arnold Lowan	Gertrude Blanch
1937 machines		
Iowa State University	John Atanasoff Clifford Berry	
Bell Labs	George Stibitz	
Harvard	Howard Aiken	
WWII: Univ. of Pennsylvania	John von Neumann Herman Goldstine	Adele Goldstine
Linear Programming	George Dantzig	Mina Rees
Handbook	Milton Abramowitz	Irene Stegun

and measures that resulted in the metric system. He formed two distinct classes of laborers, with eight planners overseeing the work of some ninety human computers.

This was the state of numerical computing when Charles Babbage attempted to produce a machine for performing such computations during the early 1820s, but his work played no role in the reform of the Greenwich Observatory in 1835 under George Airy, who employed a computing staff of young boys to work twelve-hour shifts applying basic knowledge of arithmetic, logarithms, and elementary algebra. The U.S. entered numerical computing around 1850, when the American Nautical Almanac was established in Cambridge under Charles H. Davis and the redoubtable Benjamin Peirce, who hired students like Henry Safford and John Runkle to perform needed calculations. The sole female computer on the staff was Maria Mitchell, known today as one of America's foremost early astronomers. Two other American computing facilities established about this time were the Coast Survey in Washington, D.C. (where C. S. Peirce toiled as a computer in order to avoid being drafted into the Civil War) and the Harvard Observatory (where Anna Winlock was the leading figure in an entirely female staff of human computers).

Part II deals with the issue of the mass production of machinery from the Colmar adding machine in the 1880s to IBM tabulators in the late 1920s. Those familiar with an internalistic history of mathematics in America will be exposed to an entirely different view of the 1893 Columbian Exposition in Chicago. From a mathematician's perspective the focus of the exposition was a six-day series of lectures arranged around Felix Klein. Here, however, we meet the human computers—the grunts instead of the titans. But Grier then introduces giants like Edmund Whittaker, who directed the Edinburgh Mathematics Laboratory that tabulated various Bessel functions, and Karl Pearson, whose Biometrics Laboratory performed statistical calculations. Further stratification of labor occurred in this lab with its three classes of workers: professors, students, and staff. The lab paved the way for statistics to replace astronomy as the main source of computations for needed tables. It also served the British government by producing ballistics tables for use in World War I. J. E. Littlewood helped in this effort, but, unsurprisingly, G. H. Hardy did not. There was a similar effort in the U.S., where Princeton's Oswald Veblen formed a ballistics group at the Aberdeen Proving Ground, enlisting promising graduate students and young mathematics faculty to aid in the computations. (MONTHLY readers can gain a feeling for David Grier's engaging writing style from his 2001 article on the Veblen enterprise [**3**].) A second group was established in Washington, D.C., under Chicago astronomer Forest Ray Moulton, whose computing staff included numerous women, notably chief computer Elizabeth Webb Wilson, a virtual contemporary of Grier's grandmother. Like most women, Wilson was unable to find in peacetime a position consonant with her experience, so she took a job teaching high school during the early 1920s.

Three major computing laboratories were established later in the decade within three entirely different aspects of American society: government, a university, and private industry. One was a statistical office within the Department of Agriculture under Herbert Hoover, with statistician Raymond Pearl in charge. Another was the Mathematical and Statistical Service at the University of Iowa, with support from another politician, Henry A. Wallace, who sought numerical computations for weather predictions. (It is generally known that one of the main goals of large-scale computers during World War II was meteorology, but little has been written about its prehistory.) The third major installation was AT&T's Bell Laboratories under the direction of Thornton Fry. Whereas Pearl's human computers were mostly males, the majority at Iowa were women, with Mary Clem the chief planner for the group. Human computers at Bell Labs were also mostly male, although Clara Froelich was in charge of the staff.

Grier also describes computing facilities in Great Britain and, to a lesser extent, Germany, but neither country produced facilities with human computers on a scale like the Works Project Administration (WPA), President Roosevelt's agency for alleviating unemployment during the depression. The development of both this group and a project of the National Research Council (NRC) form the core of Part III of the book. [Reader beware: an alphabet soup of initials begins here.] The NRC was established within the National Academy of Sciences in 1916 to advise the federal government on possible uses of science and technology. In 1930 the NRC formed a Subcommittee on the Bibliography of Mathematical Tables and Other Aids of Computation (MTAC), in which the expression "aids of computation" generally referred to automatic calculating machines. The MTAC got off to a rocky start, however, when its three-volume set *Tables of Higher Mathematical Formulas* was found by L. J. Comrie to be riddled with inaccuracies. The subcommittee then struggled to find an effective chair, ending up choosing Brown's A. A. Bennett in 1935. But Bennett was spread too thin and devoted little energy to the project, so after four years he was replaced by his colleague, R. C. Archibald. Although Archibald "acquired the reputation of being difficult" (p. 236), he produced impressive results. (Grier refers to Luther Eisenhart—and to Archibald—as an "applied mathematician [p. 238]". While Archibald did have a lifelong interest in tables and was responsible for founding the journal *Mathematical Tables and Other Aids to Computation* in 1943 [*Mathematics of Computation* since 1960], an equally apt description might be "historian of mathematics." Similarly, Eisenhart was generally a differential geometer.)

The WPA formed the Mathematical Tables Project (MTP) in late 1937. Two central characters in the book, Arnold Lowan and Gertrude Blanch, make their appearance here. Both held doctorates in mathematics from Ivy League universities but were unable to find satisfactory positions in academia at the height of the depression. Lowan was teaching part-time at two New York institutions when he accepted the position of MTP director. Shortly thereafter he had the fortune of recognizing one of his students on a bus, and their chance encounter led Gertrude Blanch to join the MTP as project director. Grier's account of this serendipitous meeting is captivating; I hope you will read it (pp. 203–210). Blanch directed an initial staff of 125, "as large a computing force as had ever been assembled" (p. 212), to produce tables for the National Bureau of Standards that were reviewed positively in this MONTHLY by John Curtiss and judged "free of errors" by noted critic L. J. Comrie.

Meanwhile, three machines that had their origins in computing offices in 1937 would soon compete with the MTP: the Berry-Atanasoff computer at Iowa State, one developed by George Stibitz for Bell Labs, and a third produced at Harvard by Howard Aiken. Still, the MTP did not shrink from the competition and soon saw its value rise with tables produced for the armed forces in World War II. Serving as a contractor for the Applied Mathematics Panel (AMP) when the WPA was terminated in 1943, the MTP became a professional computing organization of some three hundred human computers who turned their attention to calculations for navigation in mine clearing. Half used pencil and paper, but the other half was aided by three adding machines.

This is when Adele Goldstine appears in Grier's account. The University of Pennsylvania had the foresight to develop a computer to perform ballistic computations for Aberdeen but could not find anyone to train programmers until Adele appeared with her husband, who had been sent there with the U.S. Army. Because qualified males were scarce, Goldstine put up a "Women Only" sign outside the computing office, which she staffed by scouring women's colleges along the eastern seaboard. (Another mathematical couple that appears is John Todd and Olga Taussky.)

Flush with success, the MTP continued to compete successfully with machines after the war. Its biggest contract was with the navy under an AMP-sponsored project in which Mina Rees played a substantial role. But whereas AMP had no plans for postwar activities, Herman Goldstine and John von Neumann were already moving ahead with blueprints for improving ENIAC, arguably the first computer with stored programs. Only Goldstine's book supplies that information. Grier provides a ringing rendition of the MTP's finest hour—the solution to George Dantzig's linear programming problem that required twenty-one days from the twenty-five human computers assigned to the project. However, John von Neumann estimated that ENIAC could have solved it in nine hours, a time differential that should have put the MTP out of business. Yet the human computers persevered. Several found positions at the newly formed Institute for Numerical Analysis (INA) at UCLA. They included Gertrude Blanch, who discovered "ill conditioning" there. But in 1951 the House Un-American Activities Committee

(HUAC) found Blanch to be disloyal. The shy, retiring mathematician surprised everyone by appealing this decision; although her appeal took two years to decide, HUAC conceded that it had "no objection on grounds of loyalty."

The human computers' last hurrah took place in 1954–1964, by which time the MTP had become the Computation Laboratory of the National Bureau of Standards. The instigation occurred in 1954 when Philip Morse of MIT held a conference on computing at which the participants realized that machines did not offer all possible solutions, and a "handbook for the ordinary computer" was required. The interested reader is referred to David Grier's most recent MONTHLY article [**4**] for the details on the writing and publication of the classic book edited by Milton Abramowitz and Irene Stegun, the *Handbook of Mathematical Functions with Formulas, Graphs, and Mathematical Tables* [**1**], which has been such a resounding success that it is scheduled to be updated by 2006 as the "Digital Library of Mathematical Functions" (http://dlmf.nist.gov). The *Handbook* was the culmination of three centuries of work by human computers, and it brings the book to a glorious conclusion. Just a few weeks before the *Handbook* appeared, Gertrude Blanch was feted at the White House by President Lyndon B. Johnson, whose professional career also began with a WPA program in the 1930s. Blanch was commended for being "the top mathematician in the air force, as a founder of the scientific discipline called numerical analysis, as a patriotic citizen who has served in time of war for the Applied Mathematics Panel... who had once worked for the WPA and had once managed a staff of human computers" (p. 317).

President Johnson's eulogy brought down the curtain on human computers. Advances in supercomputers and laptops since then have dominated the landscape to such an extent that human computers have been virtually forgotten. David Grier should be congratulated for resuscitating their achievements in two main areas: developing numerical methods of scientific computation and demonstrating that computation could solve practical and important problems.

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