The Other Women of ENIAC
Rethinking IT Innovation

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www.SiliconValleyHistory.com

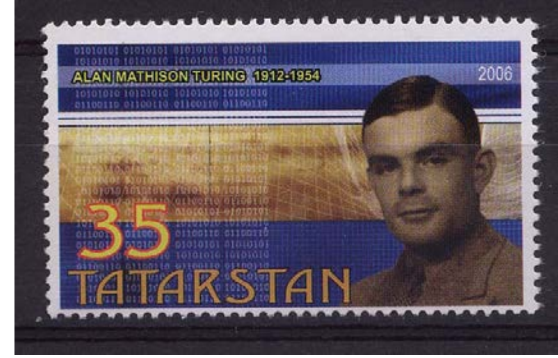
This Research Is Sponsored By

- Mrs L.D. Rope’s Second Charitable Trust
- Mrs L.D. Rope’s Third Charitable Trust

Thanks for contributions by my coauthors Mark Priestley & Crispin Rope. And to assistance from others including Ann Graf, Peter Sachs Collopy, and Stephanie Dick.

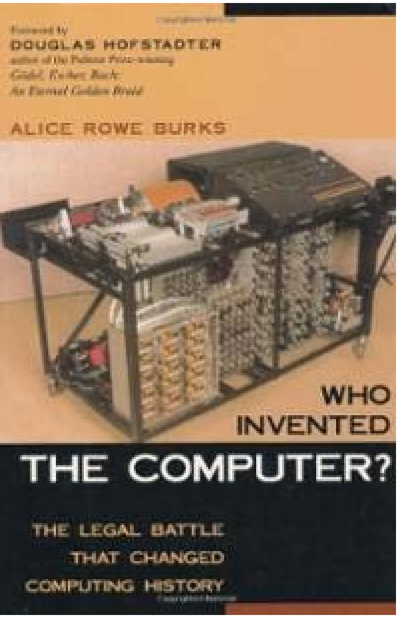
CONVENTIONAL & POPULAR HISTORY OF COMPUTING IN THE 1940S

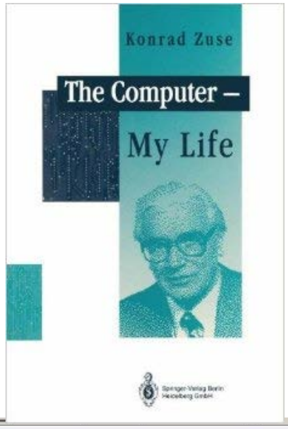
"Lone Genius" View

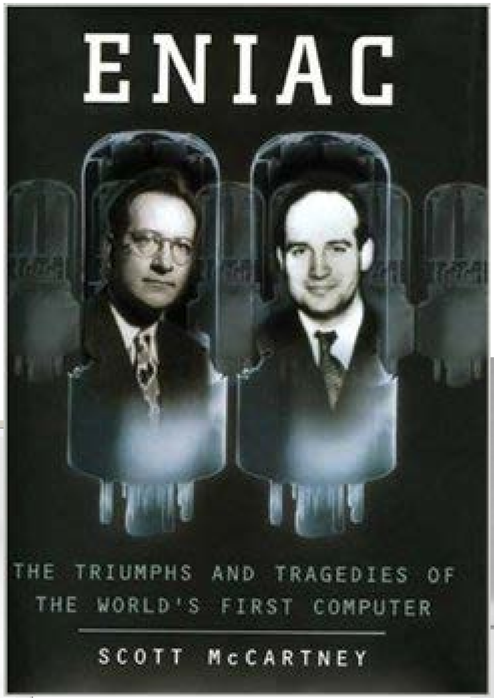


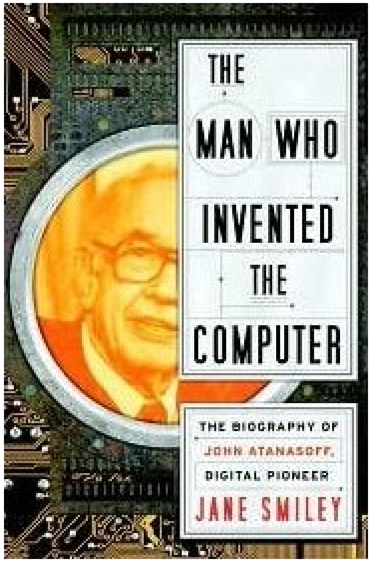
- Example Alan Turing, according to *The Imitation Game*
  - *"*I don't have time to explain myself as I go along, and I'm afraid these men will only slow me down"
- Hand building "Christopher"
  - In reality hundreds of "bombes" manufactured

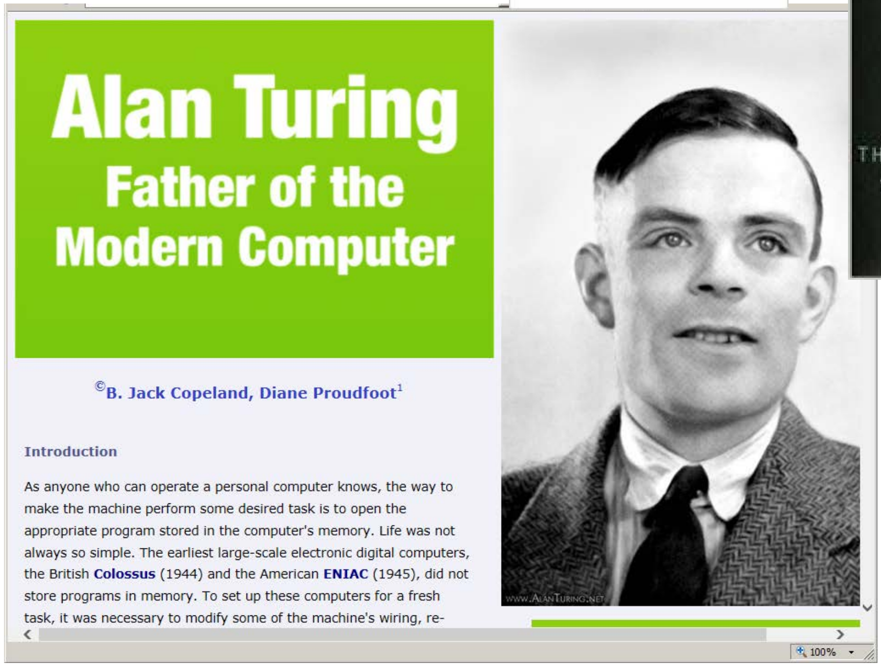
The Battle for "Firsts"

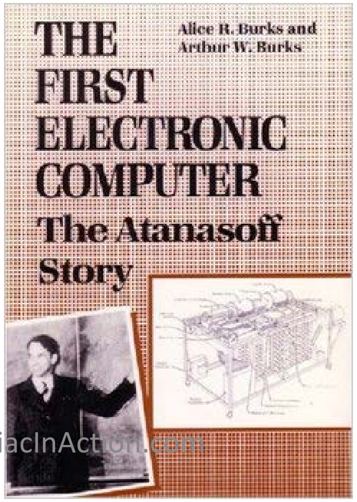


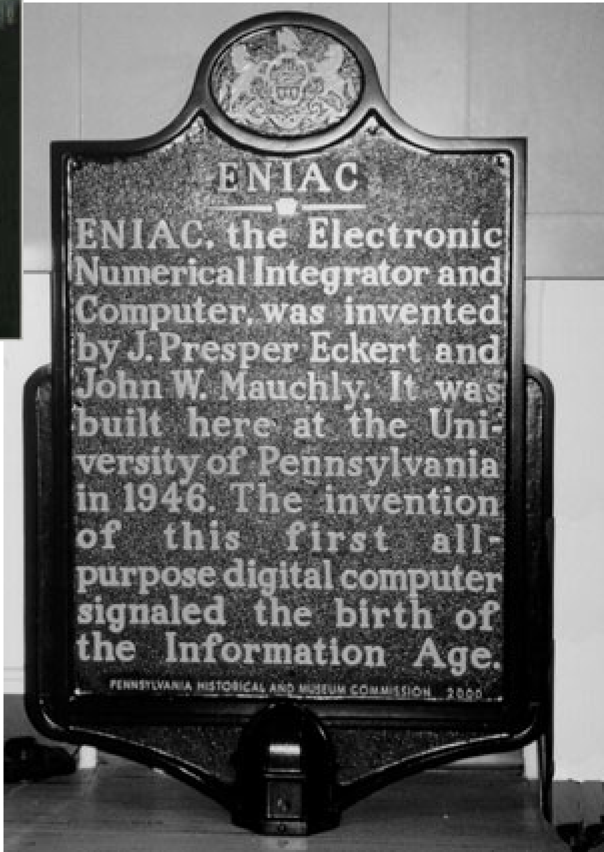






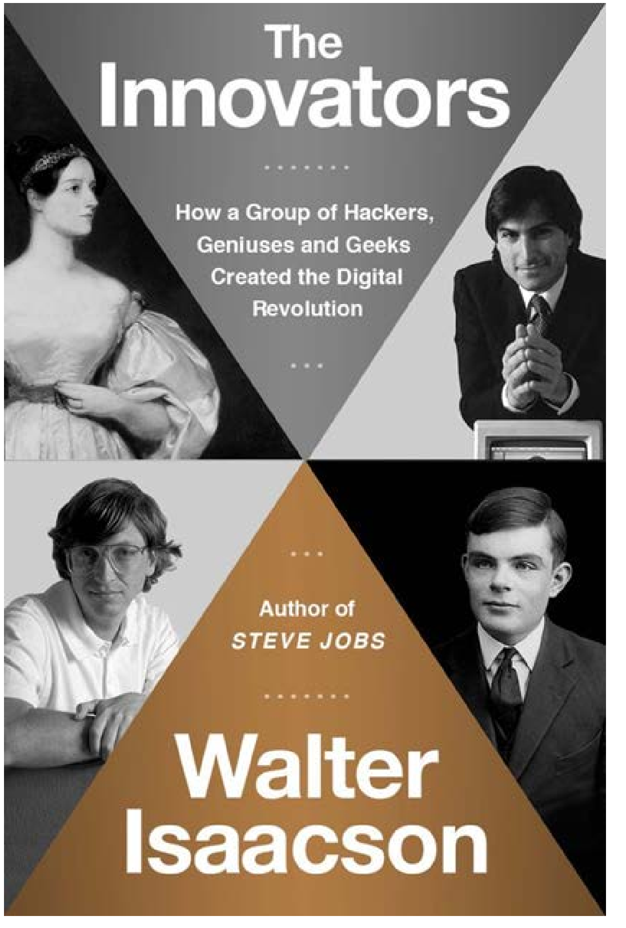






Isaacson's "The Innovators"

- Many admirable features
  - Stress on teamwork
  - Lively writing
  - References to scholarly history
  - Goes back beyond 1970s
  - Stresses role of liberal arts in tech innovation
- But going to disagree with some basic assumptions
  - Like the subtitle!



Amazon

- Isaacson has 7 of the top 10 in "Computer Industry History"
  - 4 Jobs
  - 3 Innovators

Teams of Superheroes

V viewpoints

DOI:10.1145/2804228

Thomas Haigh and Mark Priestley

Historical Reflections

Innovators Assemble: Ada Lovelace, Walter Isaacson, and the Superheroines of Computing

Can computing history be both inspiring and accurate?

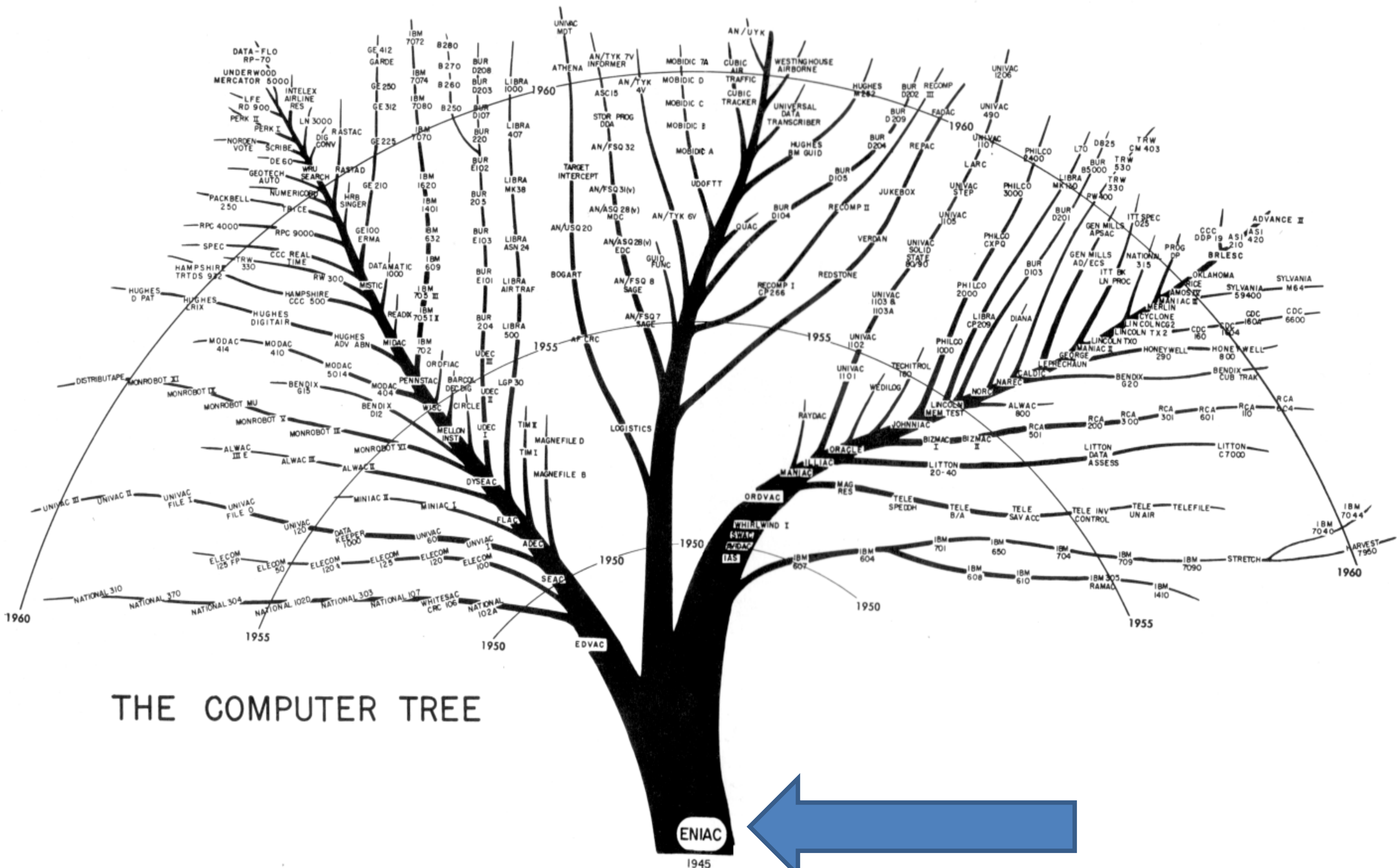
Consider two recent blockbuster sequels. *Avengers: Age of Ultron*, a superhero movie, enjoyed the second strongest opening weekend of all time, behind only its predecessor, *Avengers Assemble*. The fastest-selling history of computing book ever published is Walter Isaacson's *The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution*. Its sales fall short only in comparison to his previous book, *Steve Jobs*, which reportedly broke all records for a biography.

Avenging and innovating turn out to have a surprising amount in common. Both require one to assemble a team of superheroes who must work together to defy daunting odds and change the course of human history. Both deploy a cast of characters who have been written about for decades but are now reaching massive audiences. Both feel somewhat overstuffed, as their hugely experienced creators struggle to maintain a light touch while maneuvering a complicated narrative through a vast number of required plot points. Both highlight origin stories, as if understanding the moments at which individuals received their special powers or the circumstances in which particular technologies were first coaxed into operation will always explain their subsequent trajectories.

Isaacson's geek revolutionaries are, for the most part, entrepreneurs rather than academics. People are interested in the men behind the companies behind the gizmos of daily life, particularly if those men became spectacularly rich while exhibiting captivating flaws. Hence the wealth of books and films about Steve Jobs, Bill Gates, Mark Zuckerberg, and the early days of Google. Most of the computer science students featured in these stories dropped out part way through their degrees. Computer science has invested little effort in building and celebrating its own set of heroic role models. Individuals such as Edsger Dijkstra, Donald Knuth, and Alan Kay all have their followings but none have yet inspired a full-length biography, a statue, or a museum. Even John von Neumann has largely slipped from general awareness in the decades since his death. Perhaps computer scientists feel their discipline is doing pretty well without devoting significant energy to the construction and celebration of male heroes. Alan Turing is the exception that proves the rule here, given his gripping personal story, significant contribution to the Second World War, and crossover appeal as a gay martyr.

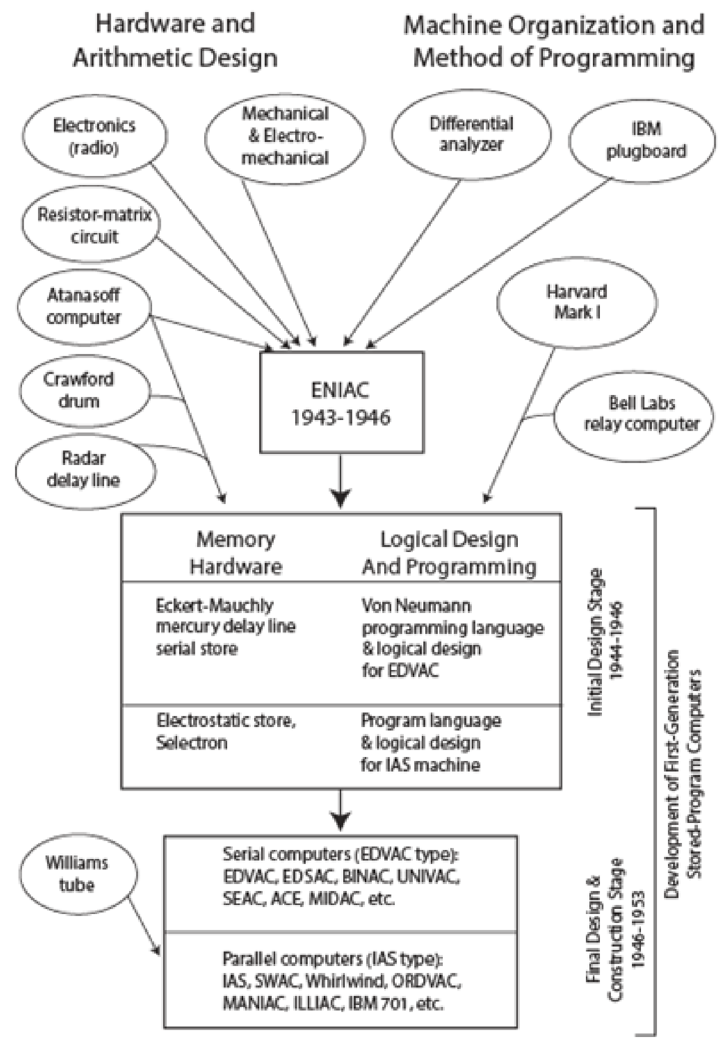
Isaacson, who has headed both CNN and *Time* Magazine, is one of the world's most successful and best-connected journalists. His titular promises of "geeks" and "genius" signal this is a fairly conservative retelling of computer history, discussing the invention of technologies rather than their commercialization or use. He arranges a series of vignettes along a familiar arc, leading from the Victorian dreams of Charles Babbage through the various computer inventors of the 1940s to the networking pioneers

The “Computer Tree”



ENIAC in Computer History

- Often called the first
  - "electronic, digital, general-purpose computer"
- A step on the path to the "first stored-program computer"



Historiography of Early Computing

- Traditional focus for the 1940s
  - Obsessed with “firsts”
  - Reduces each computer to a single date of first operation
  - Considers only architectural innovations
  - Doesn’t care about what computers were used for
- This leaves out an enormous amount!
- Hence: *ENIAC in Action*

DESIGNING ENIAC

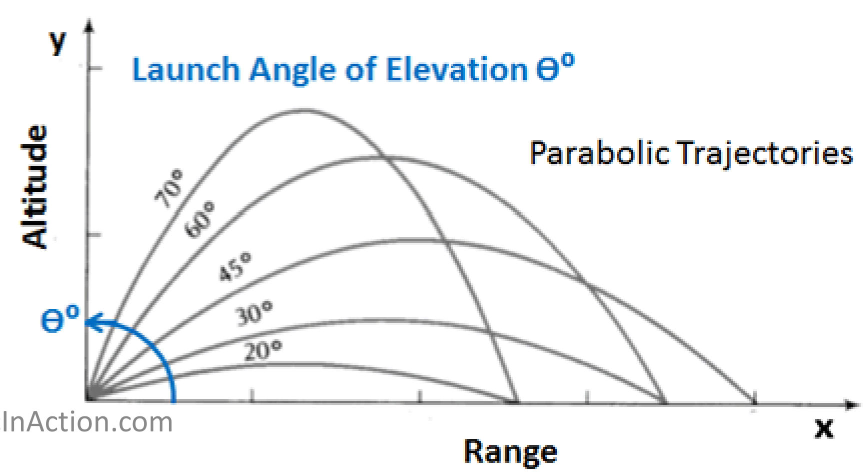
Sponsor: U.S. Army

- Ballistics Research Laboratory
  - Part of Aberdeen Proving Ground, which was part of the Ordnance Department

TABLE II.—PART OF A FIRING TABLE FOR 75-MILLIMETER GUN

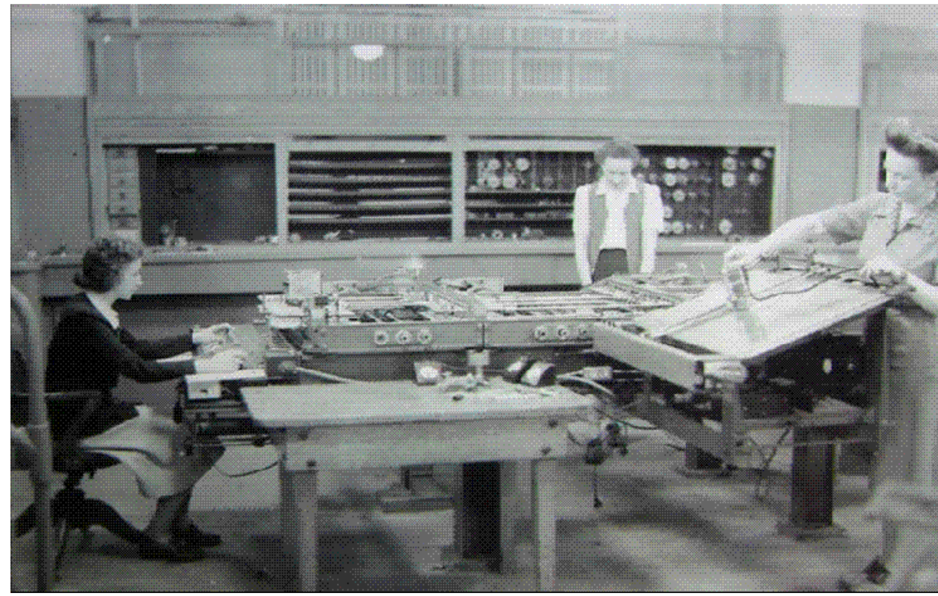
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
						Probable error					Deflection effect		Complementary angle of site for each		Range effect of increase of				
Range	Elevation	Fork	Change in elevation for 100-yd. change in range	Change in range for 1-mil change in elevation	Time of flight	Range	Deflection	Height of burst	Slope of fall	Line number of metro message	Drift*	Lateral wind of 1 m.p.h. (+)	+1 mil of site	−1 mil of site	One per cent in weight of projectile standard weight 15.96 lb.	One foot per second in MV	Air temperature 1°. Standard is 59°F.	Rear wind 1 m.p.h.	One per cent in air density
R	El	F	c	1 mil	Time	ePr	ePd		Slope	Line	Dft.	W-D			Wt.	VE	Temp.	W-R	Den.
yd.	m̸	m̸	m̸	yd.	sec.	yd.	yd.	m̸	1/-	No.	m̸	m̸	m̸	m̸	yd.	yd.	yd.	yd.	yd.
4000	122.0	2	4.6	22	10.2	11	1	1	5.5	1	R 4	.4	+.01	−.01	−1	+2.3	+1.1	+3.7	−14
4100	126.6	2	4.6	21	10.5	12	2	1	5.3	1	R 4	.4	+.01	−.01	−1	+2.4	+1.2	+3.8	−14
4200	131.4	2	4.8	21	10.9	12	2	1	5.1	1	R 4	.4	+.01	−.01	−1	+2.4	+1.2	+4.0	−15
4300	136.2	2	4.8	21	11.2	12	2	1	4.9	1	R 4	.5	+.02	−.02	0	+2.4	+1.3	+4.2	−15
4400	141.0	2	4.8	20	11.6	12	2	1	4.7	1	R 4	.5	+.02	−.02	0	+2.5	+1.4	+4.4	−15
4500	146.0	2	5.0	20	11.9	12	2	1	4.5	2	R 4	.5	+.02	−.02	0	+2.5	+1.4	+4.6	−16
4600	151.0	3	5.0	20	12.3	12	2	1	4.3	2	R 4	.5	+.02	−.02	0	+2.5	+1.5	+4.8	−16
4700	156.0	3	5.0	19	12.6	12	2	1	4.2	2	R 4	.5	+.02	−.02	+1	+2.5	+1.6	+5.0	−16
4800	161.2	3	5.2	19	13.0	12	2	1	4.0	2	R 5	.5	+.02	−.02	+1	+2.6	+1.7	+5.2	−17
4900	166.6	3	5.2	19	13.3	13	2	1	3.9	2	R 5	.5	+.02	−.02	+1	+2.6	+1.7	+5.4	−17
5000	172.0	3	5.4	19	13.7	13	3	1	3.7	2	R 5	.5	+.02	−.02	+2	+2.6	+1.8	+5.6	−18
5100	177.6	3	5.4	18	14.0	13	3	1	3.6	2	R 5	.5	+.02	−.02	+2	+2.6	+1.9	+5.8	−18
5200	183.2	3	5.6	18	14.4	13	3	1	3.5	2	R 5	.5	+.03	−.03	+2	+2.6	+1.9	+6.0	−19
5300	188.8	3	5.6	18	14.8	14	3	1	3.4	2	R 6	.6	+.03	−.03	+2	+2.6	+2.0	+6.2	−19
5400	194.4	3	5.8	17	15.2	14	3	1	3.2	2	R 6	.6	+.03	−.03	+3	+2.7	+2.1	+6.4	−20
5500	200.2	3	5.8	17	15.6	14	3	1	3.1	2	R 6	.6	+.03	−.03	+3	+2.7	+2.2	+6.7	−20

Range R vs Launch Angle Θ for a Given Initial Velocity V_0



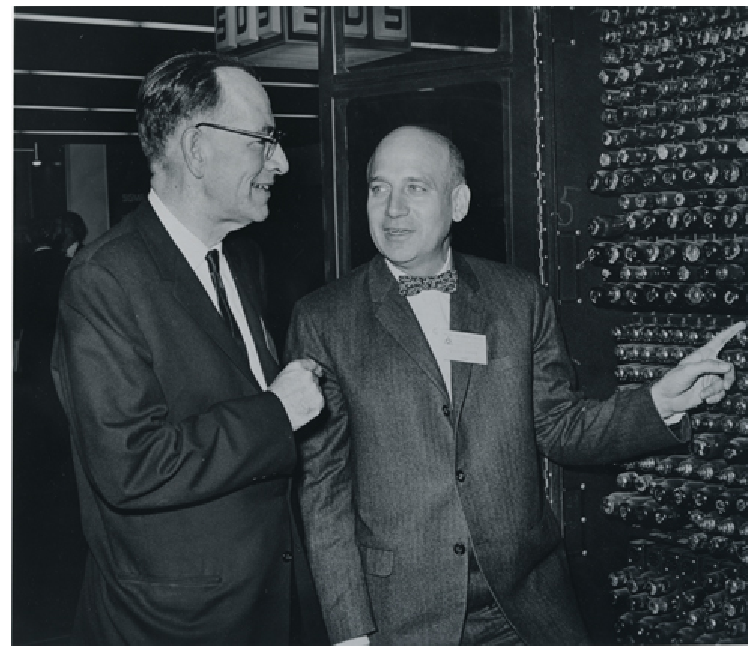
Created by the University of Pennsylvania

- Moore School of Electrical Engineering
  - Founded 1923
  - Strong ties to local electronics industry
  - Had already partnered with BRL to build "differential analyzer" and carry out hand computations
  - Fairly small



Project Initiators

- John W. Mauchly
  - Ph.D. physicist, now teaching at the Moore School after taking a summer course in electronics
- J. Presper Eckert
  - Star electrical engineering student, recently recruited to the laboratory staff for war projects



ENIAC Life Story

- 1943: Proposed and approved. Design work.
- 1944: Details plans and prototyping work
- 1945: Main construction & debugging.
- 1946: Experimental use at Moore School.
- 1947: Reassembled and tested at the Ballistics Research Laboratory
- 1948-1954. Intensive use at BRL
- 1955: Decommissioned

Engineering Team

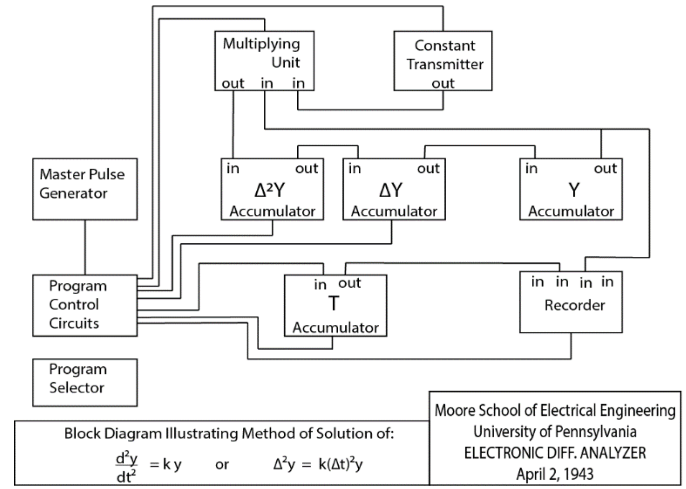
- T. Kite Sharpless
- Arthur Burks
- Robert Shaw
- Joseph Chedaker
- Chuan Chu
- Frank Mural
- And others…

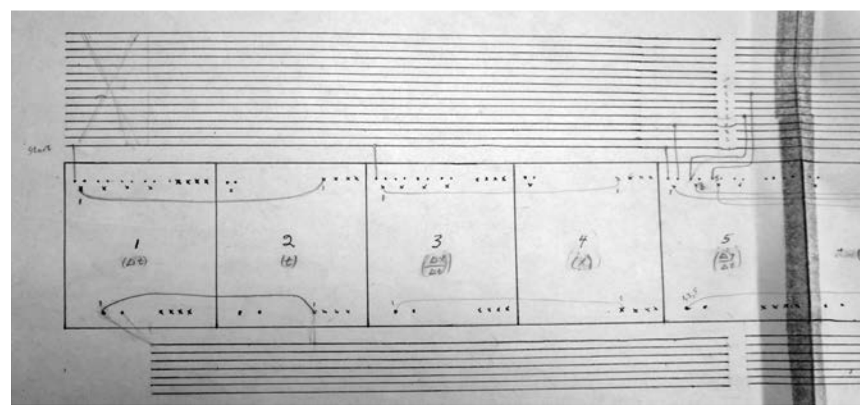
Other Forms of Labor

- Moore School:
  - Harold Pender, Dean
  - John Grist Brainerd, Project Director
  - Isabelle Jay, secretary
  - Marjorie Santa Maria, draughtswoman
- Elsewhere in Penn:
  - Hans Rademacher, numerical methods expert
  - Legal and contract specialists
- BRL:
  - Herman Goldstine, oversaw BRL work at Moore School
  - Paul Gillon, Goldstine's boss
  - Leland Cunningham, head of machine computation group
  - Derek Lehmer & Haskell Curry,
    mathematical would-be users

Structured from Mathematical Analysis

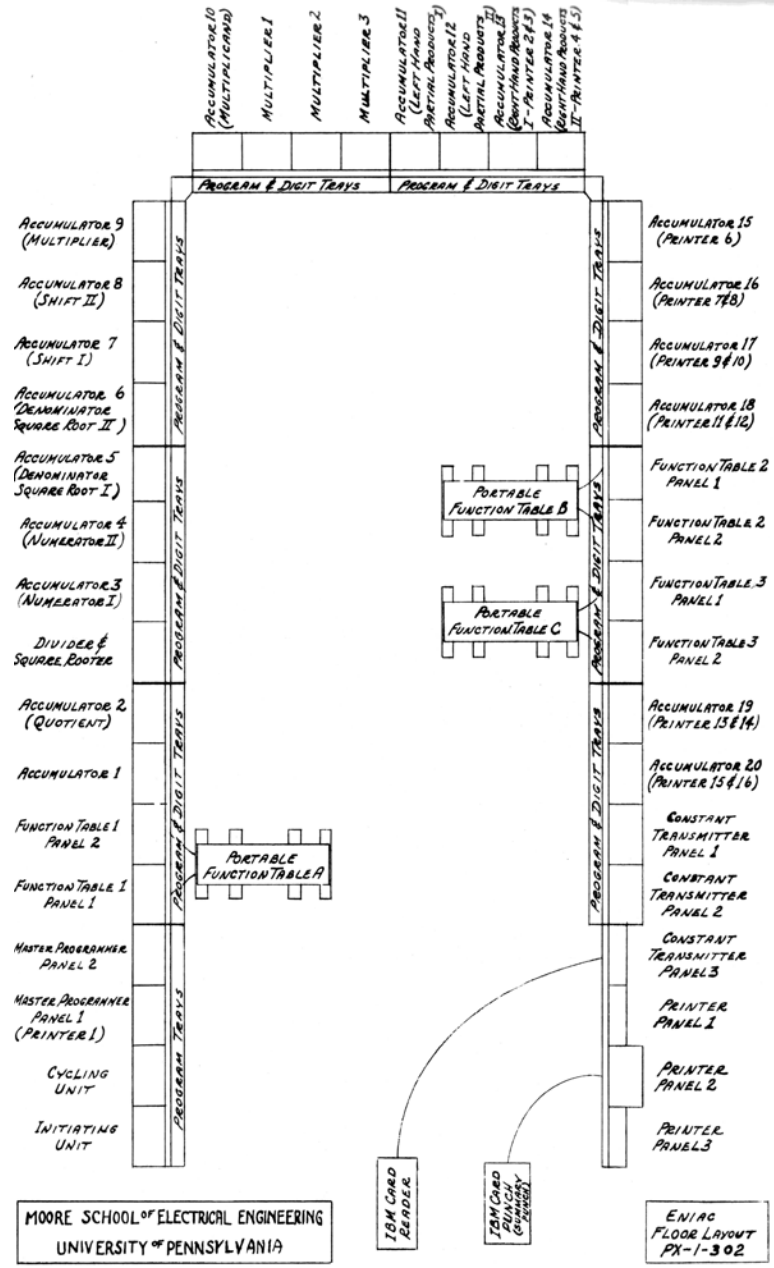
- Detailed analysis of the firing tables problem in 1943 guided ENIAC's fundamental design
- But it could tackle many other kinds of problem





Unique Architecture

- Wires route control pulses from one unit to another
- Switches determine what happens when a pulse arrives
- Data flows on ad-hoc busses

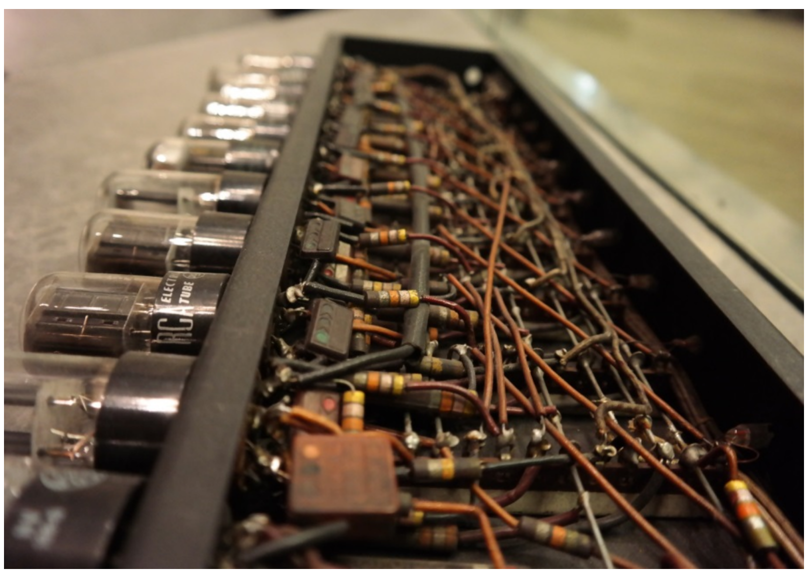


Technical Specifications

- Cost: Circa $500,000 excluding delivery
  – Up from initial budget of $150,000
- Size: About 2,000 square feet
- Weight: About 30 tons
- Power consumption: 150KW
- Memory (RAM): 200 decimal digits
- Memory (ROM): 4000 decimal digits
- Multiplications per second: approx 300

ENIAC Storage

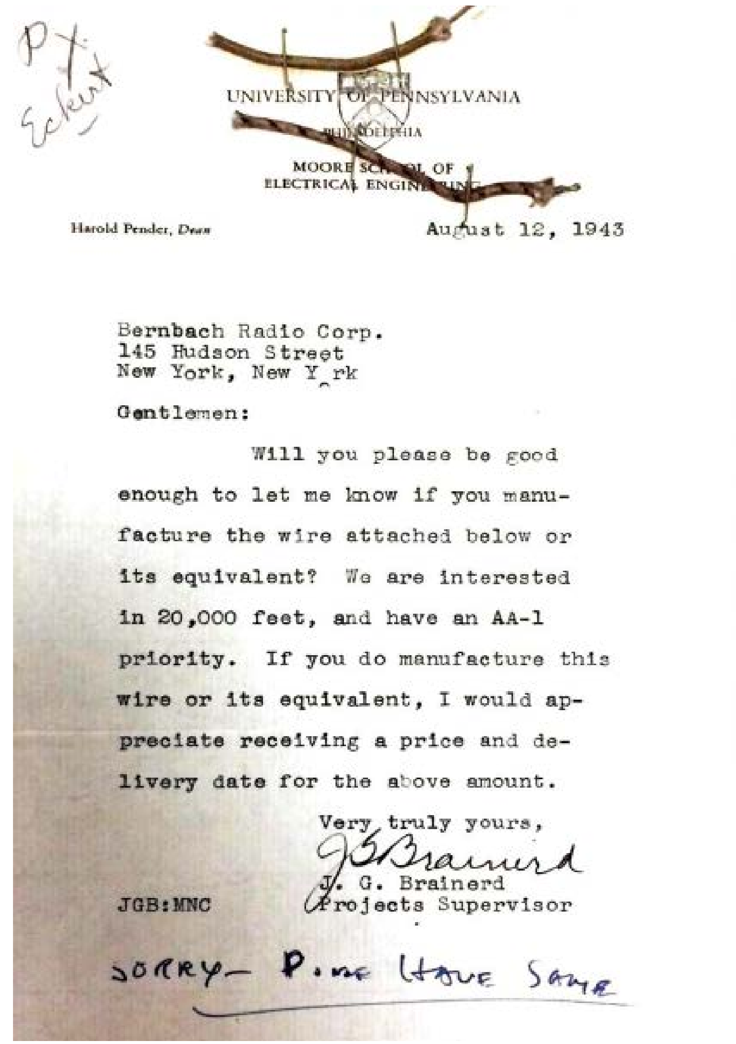
- Each decimal digit was a “plug-in” module with 23 vacuum tubes



BUILDING ENIAC

Procurement Challenges

- Challenging to source large quantities of high performance components in war economy
  - Even wire!
  - Precision resistors
  - Custom power supplies
    - 78 voltage levels from 28 different power supplies



UNIVERSITY OF PENNSYLVANIA
PHILADELPHIA

MOORE SCHOOL OF
ELECTRICAL ENGINEERING

Harold Pender, *Dean*

August 12, 1943

Bernbach Radio Corp.
145 Hudson Street
New York, New York

Gentlemen:

Will you please be good enough to let me know if you manufacture the wire attached below or its equivalent? We are interested in 20,000 feet, and have an AA-1 priority. If you do manufacture this wire or its equivalent, I would appreciate receiving a price and delivery date for the above amount.

Very truly yours,

J. G. Brainerd
J. G. Brainerd
Projects Supervisor

JGB:MNC

SORRY— [illegible] HAVE SAME

Physical Construction

- Project staff size increased rapidly in 1944 as production work began
- Split into separate groups for
  - Engineering & Test (7 design engineers)
  - Mechanical Design & Drafting (3 people)
  - Model Making Team (3 people)
  - Production team (34 FTE workers by end of 1944)
- Formal approval process needed to move designs from one group to another

Some Forgotten Women

- Accounting & personnel records show
  - "Wiremen"
  - "Technicians"
  - "Assemblers"

(6)

MOORE SCHOOL PROJECT - PX #2 NOV 1944

DATE	EXPLANATION	DEPT. REQ. NO.	CODE NO.	EXPENDITURES	RECEIPTS	UNEXPENDED BALANCE
NOV	CARRIED FORWARD					16,757.61
NOV 30	SALARIES---		SAL			
	G MOERMAN			210.63		
	J P MOORE			253.08		
	F MURB			316.66		
	J E NOLAN			49.38		
	WM NOLAN			168.00		15,708.86
	VIOLET PAIGE			51.00		
	C C PARKER			309.69		
	R J PEOPLES			47.50		
	JANE PEPPER			150.00		
	ALICE PRITCHETT			229.32		
	JAMES REID			6.00		
	S ROSENTHAL			322.88		
	RUTH RUCH			246.42		
	MARJORIE SANTA MARIA			30.00		
	T K SHARPLESS			316.66		
	R F SHAW			291.66		
	ELEANOR SIMONE			252.37		
	CAROLYN SHIERMAN			230.06		
	DOROTHY SHISLER			86.66		
	JAMES SMITH			392.21		
	FRANCIS SPUNIER			231.39		
	A T STEVENS			265.10		
	P SULLIVAN			371.10		
	S P THALAN			146.85		
	EVANGELINE WERLEY			88.17		
	DIANA WRENN			134.67		11,560.15
				5197.46 ok		

Please check with Departmental requisitions issued against this account and if statement does not agree, communicate with the Comptroller's Office.

Date 4/10/44

Mr. H. I. MacLean, Comptroller
207 S. 36th Street

Dear Mr. MacLean:

Will you please be good enough to ~~xxxxx~~ make the payments indicated below. until further notice.

Very truly yours,

Dean.

Name as it should appear on check	Reason for payment	Time interval covered by payment	Payment	Account against which payment is to be charged.
Frances Spurrier	Promotion from Trainee to Assistant Technician	Beginning April 3, 1944 increase the salary of Mrs. Spurrier from $1850 per year to $2000 per year.		PX #2

Almost 50 confirmed "ENIAC Women" In 1944 Alone

15. We found the names of ENIAC workers in the detailed, tabulated accounting statements for "Project PX-2" in MSOD-UP, box 48 (MS-112). These list the full names of most em-

than remember them here, as literal footnotes to the project's history. Let the record show that among the women who helped to design and build ENIAC during 1944 were Viola Andreoni, Martha Bobe, Lydia R. Bell, Vava Callison, Nellie T. Collett, O'Bera Darling, Helen Anna De Lacy, Jeanette M. Edelsack (draftswoman), Theresa Fraley, Gertrude E. Gilbert, Ann Gintis, Rita Golden, Margaret Henshaw, Jane Hodes, Virginia Humprey, Mary Ann Isreall, Dorothy F. Keller, Mary Knos, Alice T. Larsen, Alma Markward (assembler), Mary Martin, Anne D. McBride, Cathrine J. McCann (draftswoman), Rose McDonough, Mary E. McGrath, Mary McNetchell, Gertrude Moriarty, Anna Munson, Ann O'Neill, Violet Paige, Jane L. Pepper (draftswoman), Alice Pritchett, Ruth Ruch, Marjorie Santa Maria (draftswoman), Nancy Sellers, Eleanor Simone (technician), Carolyn Shearman, Dorothy K. Shisler, Frances Spurrier, Grace M. Warner, Evangeline E. Werley, Charlotte Widcamp, Sally Wilson, Diana Wrenn, and Isabelle Jay (secretary).

Spurrier, Grace M. Warner, Evangeline E. Werley, Charlotte Widcamp, Sally Wilson, Diana Wrenn, and Isabelle Jay (secretary).

Spinning Progress to Sponsors

- By 1944 the end of the war is clearly approaching
  - May 26, 1944: Goldstine promises completion “by October 1”
  - August 1944, will be “virtually completed” by the end of 1944
  - Sept 1944, work is “on the fairways”
  - December 1944, “in the throes of completing the production of the ENIAC… within the next two months”
  - May 1945, “on the home stretch” with testing starting “about 2 weeks from now.”

Launch Day: 15 February, 1946

PROGRAM

Speakers

The President of the University of Pennsylvania
DR. GEORGE WM. MCCLELLAND

The President of the National Academy of Sciences
DR. FRANK B. JEWETT

The Chief of the Research and Development Service, Ordnance Department, United States Army
MAJOR GENERAL GLADEON M. BARNES

The Dedication of the ENIAC (Information confidential until released)

The Electronic Numerical Integrator and Computer — the ENIAC — is the fastest computing machine ever developed. It will perform more than one million additions or subtractions of ten-figure numbers in five minutes, more than a million multiplications in an hour. It can be used in the solution of mathematical problems from the simplest to the most abstruse and of many problems previously not capable of solution.

Under the direction of the Ordnance Department, United States Army, the ENIAC was developed by the Moore School of Electrical Engineering of the University of Pennsylvania. The dedication of this pioneering scientific achievement will mark the initial release of information to the public and the first viewing of the ENIAC.

MENU

Bisque of Lobster

Filet Mignon Au Jus
or
Broiled Salmon Steak

Fresh String Beans — Au Gratin Potatoes

Hearts of Lettuce, French Dressing

Cheese — Crackers

Ice Cream — Fancy Cakes

Cafe

NY Times 15 Feb, 1946

- Based on earlier, Feb 1 1946 demo for journalists

Electronic Computer Flashes Answers, May Speed Engineering

By T. R. KENNEDY Jr.

Special to THE NEW YORK TIMES.

PHILADELPHIA, Feb. 14—One of the war's top secrets, an amazing machine which applies electronic speeds for the first time to mathematical tasks hitherto too difficult and cumbersome for solution, was announced here tonight by the War Department. Leaders who saw the device in action for the first time heralded it as a tool with which to begin to rebuild scientific affairs on new foundations.

Such instruments, it was said, could revolutionize modern engineering, bring on a new epoch of industrial design, and eventually eliminate much slow and costly trial-and-error development work now deemed necessary in the fashioning of intricate machines. Heretofore, sheer mathematical difficulties have often forced designers to accept inferior solutions of their problems, with higher costs and slower progress.

The "Eniac," as the new electronic speed marvel is known, virtually eliminates time in doing such jobs. Its inventors say it computes a mathematical problem 1,000 times faster than it has ever been done before.

The machine is being used on a problem in nuclear physics.

The Eniac, known more formally as "the electronic numerical integrator and computer," has not a single moving mechanical part. Nothing inside its 18,000 vacuum tubes and several miles of wiring moves except the tiniest elements of matter-electrons. There are, however, mechanical devices associated with it which translate or "interpret" the mathematical language of man to terms understood by the Eniac, and vice versa.

Ceremonies dedicating the machine will be held tomorrow night at a dinner given a group of Government and scientific men at the University of Pennsylvania, after

5, Column 3

Continued From Page 1

which they will witness the Eniac in action at the Moore School of Electrical Engineering, where it was built with the assistance of the Army Ordnance Department.

The Eniac was invented and perfected by two young scientists of the school, Dr. John William Mauchly, 38, a physicist and amateur meteorologist, and his associate, J. Presper Eckert Jr., 26, chief engineer of the project. Assistance also was given by many others at the school.

Army ordnance men had been on the lookout for a machine with which to prepare a large volume of ballistic data, which in turn was needed to break a threatened bottleneck in the production of firing and bombing tables for new offensive weapons going overseas. Without the tables the guns could not be used effectively.

Project Took Thirty Months

Capt. H. H. Goldstine, Army ordnahce mathematician, then at the school, heard of Dr. Mauchly's ideas, told Col. Paul N. Gillon of the Aberdeen (Md.) Proving Ground, enlisted his enthusiastic support and the project went forward with Government aid. Thirty months to the day later it was finished and operating, doing easily what had been done laboriously by many trained men. The Eniac soon will be permanently installed at Aberdeen.

"A very difficult wartime problem" was sent through its intricate circuits soon after it was completed. The Eniac completed the task in two hours. Had it not been available the job would have kept busy 100 trained men for a whole year. So clever is the device that its creators have given up trying to find problems so long that they cannot be solved.

This resolver of difficult problems is what computing experts call a "digital" counter. Basically, it does nothing more than add, subtract, multiply and divide. It does this by generating very accurately timed electrical impulses at a speed of 100,000 per second, and can do one operation every twentieth pulse, thereby adding, for instance, at the rate of 5,000 per second.

Since all mathematical tasks, no matter how abstruse or involved, can be resolved to basic arithmetic if enough time is available, the Eniac can reverse the process, eliminate time, and arrive at an answer to virtually any problem. So say its inventors.

Machine Has Memory, Too

The machine, however, can do much more. It has the human faculty of "memory," four kinds of it, to perform certain tasks in the proper sequence. It also has "control" elements, and can, up to a point, dictate its own action. It can, for instance, compare two numbers and, depending on which one is larger, choose one of two possible courses.

First, it gets its original numbers from a series of cards in which holes are punched to indicate the "initial and boundary conditions" of the problem. One of the Eniac "minds" performs this job.

When the problem is punched on the cards they are dropped into a slot in a "reader." The man who wants the answers may then sit down and await results. He seldom has to wait long; the Eniac does most of its tasks in seconds.

A unit called "a master programmer" oversees the whole computation and makes sure it is carried out.

The Eniac has some 40 panels nine feet high, which bristle with control and indicating material. Pink neon lights blink on several panels as buttons are pressed. Numbers are printed beside the lights.

Those who witnessed the demonstration entered a 30-by 60-foot room. The computer took up most of the space.

Dr. Arthur W. Burks of the Moore School explained that the basic arithmetical operations, if made to take place rapidly enough, might in time solve almost any problem.

"Before You Can Say . . ."

"Watch closely, you may miss it," he asked, as a button was pressed to multiply 97,367 by itself 5,000 times. Most of the onlookers missed it—the operation took place in less than the wink of an eye.

To demonstrate the Eniac's extreme speed, Dr. Burks next slowed down the action by a factor of 1,000 and did the same problem. Had the visitors been content to wait 16 2-3 minutes they could have observed the answer in neon light. The next was multiplication—13,975 by 13,975. In a flash the quotient appeared—195,300,625. A table of squares and cubes of numbers was generated in one-tenth of a second. Next, a similar one of sines and cosines. The job was finished and printed on a large sheet before most of the visitors could go from one room to another.

The Eniac was then told to solve a difficult problem that would have required several weeks' work by a trained man. The Eniac did it in exactly fifteen seconds.

All problems must first be resolved to their essentials, punched on cards and run through an International Business Machines unit called a "reader." The reader translates the mathematical language to that of the Eniac, and vice versa. When this is done the machine is ready to operate. Numerical values covering a wide range of scientific "constants" are interjected as and when they are needed. There are four kinds of "memory" in the Eniac to accomplish this. Constant adjustments are made in advance for each type of problem.

Normally the Eniac handles ten-digit numbers—a billion, for instance—but it can handle twenty-digit numbers just as easily, resulting in number running to astronomical size.

Machine Cost $400,000

More than 200,000 man-hours went into the building of the machine. It contains more than half a million soldered joints, and cost about $400,000. Three times as much electricity is required to operate it as for one of our largest broadcasters—150 kilowatts.

Little more than three years ago the Eniac was only an idea; today it is perhaps the greatest marvel of electronic ingenuity. Dr. Mauchly joined the Moore School staff in 1941, hoping he might be able to realize his ambition, to revolutionize the art of dealing with huge numbers in complex form. He believed, for instance, that something could be done about long-range weather predicting.

In the field of peacetime activities Dr. Mauchly foresees not only better weather-predicting—months ahead—but also better airplanes, gas turbines, micro-wave radio tubes, television, prime movers, projectiles operating at supersonic speeds carrying cargoes in peace and even more and better accuracies in studying the movements of the planets.

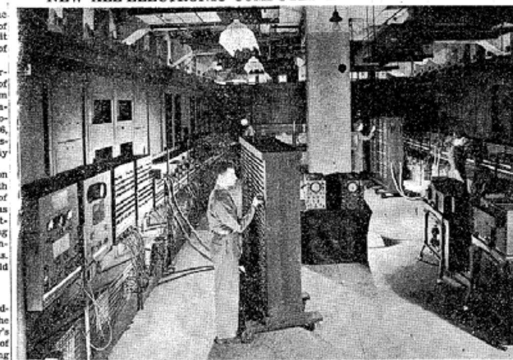
According to Colonel Goldstine "mountainous" computational burdens have been carried by scientists in the past, which will be largely removed by electronic computers. He pointed out that the solution of equations of motion has been a hindrance in the past and that studies of shell flight, high speed planes, rockets and bomb are "a few of the fields that will benefit hugely through electronic computing."

Mr. Eckert predicted an era which, with electronic speed available, problems that have been thought impossible because they might require a lifetime will be readily resolved for man's use.

"The old era is going, the new one of electronic speed is on the way, when we can begin all over again to tackle scientific problems with new understanding," he told reporters.

Mr. Eckert briefly described the Harvard and Massachusetts Institute of Technology mechanical and electro-mechanical computing machines, the most recent of which was announced only a few months ago.

NEW ALL-ELECTRONIC COMPUTER AND ITS INVENTORS



An overall view of "ENIAC" showing attendants preparing the machine to solve a hydrodynamical problem. In a matter of seconds it does what trained computers hitherto have required weeks to perform. The instrument contains 18,000 vacuum tubes, occupies a room 30 by 60 feet and weighs thirty tons. It took thirty months to build, cost about $400,000 and required 200,000 man-hours of work.

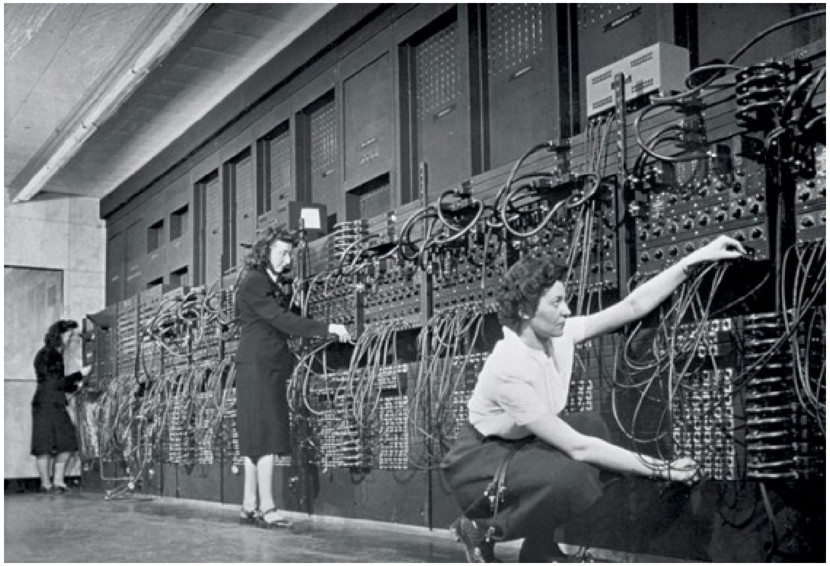
Dr. John W. Mauchly

J. Presper Eckert Jr.

OPERATING ENIAC

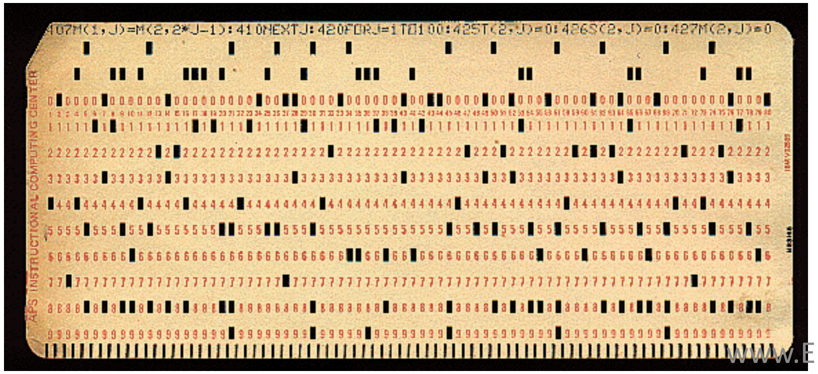
The Operators

- Six women selected summer 1945
  - Had previously been computing trajectories manually
- Operated ENIAC at the Moore School
  - Some transitioned back to Aberdeen
- Duties included
  - Configuring and wiring units from paper plans
  - Helping to diagnose and correct problems
  - Feeding cards in and out of ENIAC
  - Working the auxiliary punched card equipment
  - Working with scientific users to design ENIAC setups

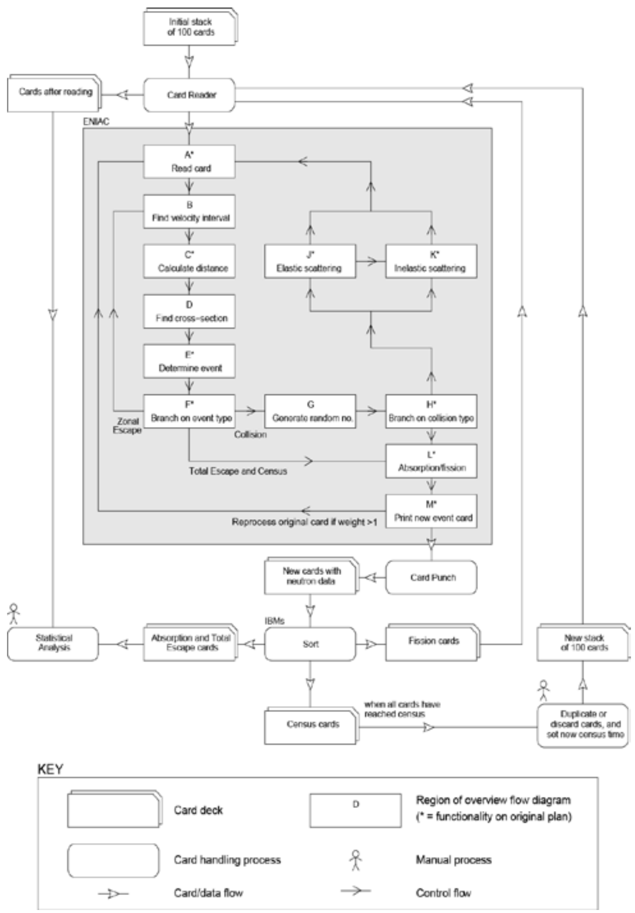


Punched Card Machines

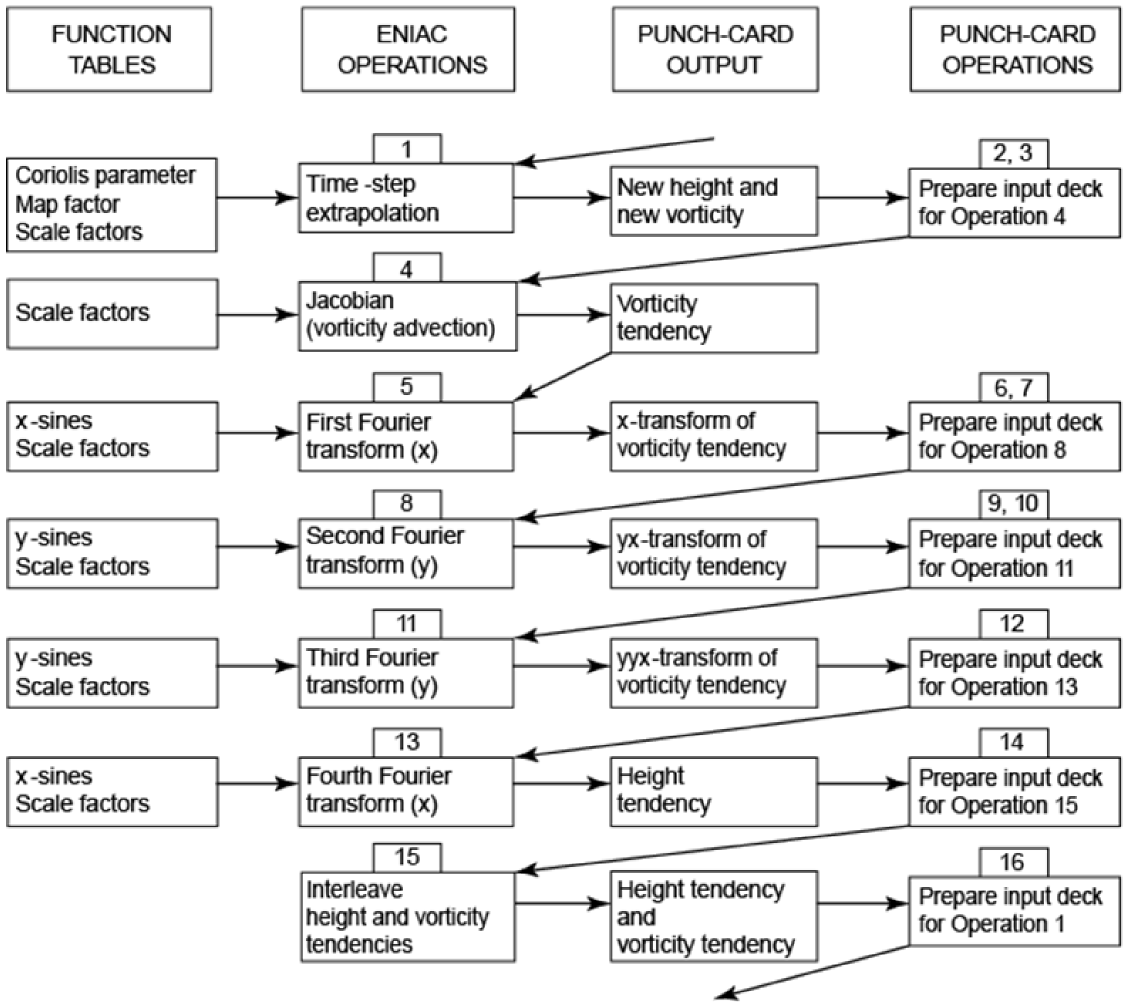
- Specialized units
  - Sorter
  - Collator
  - Punch
  - Tabulator
- Human operators reconfigure machines and move cards between them



ENIAC as Part of a Bigger System



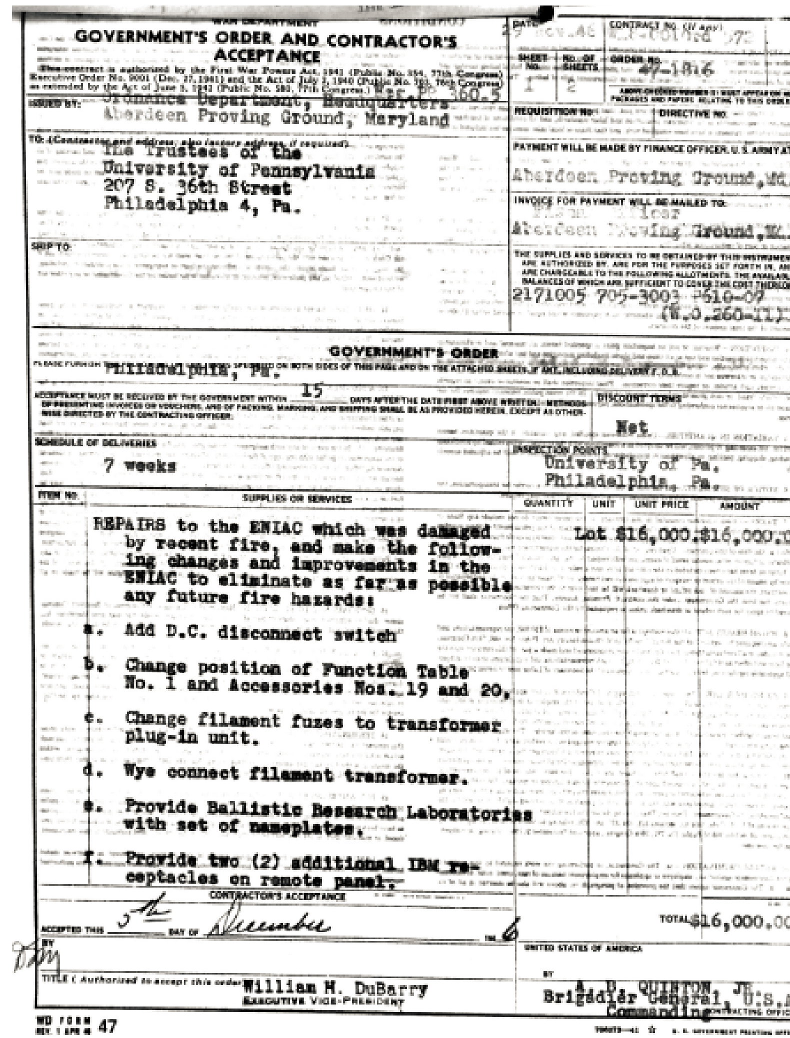
Weather Prediction Application (1950)



ENIAC AS A MATERIAL SPACE

Poor Conditions at Moore School

- Floods in October & December 1945
  - December 25 flood from snow melt, Mauchly went home at 3am leaving "about five men still working, mopping up water and emptying buckets which catch drips."
- Fire on October 26, 1945
  - Shutdown circuits on blowers prevent spread to other panels



WAR DEPARTMENT

GOVERNMENT'S ORDER AND CONTRACTOR'S ACCEPTANCE

This contract is authorized by the First War Powers Act, 1941 (Public No. 354, 77th Congress) Executive Order No. 9001 (Dec. 27, 1941) and the Act of July 2, 1940 (Public No. 703, 76th Congress) as extended by the Act of June 5, 1942 (Public No. 580, 77th Congress.)

DATE: 29 Nov. 46

CONTRACT NO. (if any):

SHEET NO.: 1 | NO. OF SHEETS: 2

ORDER NO.: 47-1816

ISSUED BY: Ordnance Department, Headquarters Aberdeen Proving Ground, Maryland

REQUISITION NO.: | DIRECTIVE NO.:

TO: (Contractor and address; also factory address, if required)
The Trustees of the
University of Pennsylvania
207 S. 36th Street
Philadelphia 4, Pa.

PAYMENT WILL BE MADE BY FINANCE OFFICER, U.S. ARMY AT: Aberdeen Proving Ground, Md.

INVOICE FOR PAYMENT WILL BE MAILED TO: Aberdeen Proving Ground, Md.

SHIP TO:

THE SUPPLIES AND SERVICES TO BE OBTAINED BY THIS INSTRUMENT ARE AUTHORIZED BY, ARE FOR THE PURPOSES SET FORTH IN, AND ARE CHARGEABLE TO THE FOLLOWING ALLOTMENTS, THE AVAILABLE BALANCES OF WHICH ARE SUFFICIENT TO COVER THE COST THEREOF:
2171005 705-3003 P610-07 (W.O.260-11)

GOVERNMENT'S ORDER

PLEASE FURNISH ... SPECIFIED ON BOTH SIDES OF THIS PAGE AND ON THE ATTACHED SHEETS, IF ANY, INCLUDING DELIVERY F.O.B. Philadelphia, Pa.

ACCEPTANCE MUST BE RECEIVED BY THE GOVERNMENT WITHIN 15 DAYS AFTER THE DATE FIRST ABOVE WRITTEN. METHODS OF PRESENTING INVOICES OR VOUCHERS, AND OF PACKING, MARKING, AND SHIPPING SHALL BE AS PROVIDED HEREIN, EXCEPT AS OTHERWISE DIRECTED BY THE CONTRACTING OFFICER.

DISCOUNT TERMS: Net

SCHEDULE OF DELIVERIES: 7 weeks

INSPECTION POINTS: University of Pa. Philadelphia, Pa.

ITEM No.	SUPPLIES OR SERVICES	QUANTITY	UNIT	UNIT PRICE	AMOUNT
	REPAIRS to the ENIAC which was damaged by recent fire, and make the following changes and improvements in the ENIAC to eliminate as far as possible any future fire hazards:	Lot		$16,000.	$16,000.00
a.	Add D.C. disconnect switch				
b.	Change position of Function Table No. 1 and Accessories Nos. 19 and 20.				
c.	Change filament fuzes to transformer plug-in unit.				
d.	Wye connect filament transformer.				
e.	Provide Ballistic Research Laboratories with set of nameplates.				
f.	Provide two (2) additional IBM receptacles on remote panel.				

CONTRACTOR'S ACCEPTANCE

ACCEPTED THIS 5th DAY OF December 1946

TOTAL $16,000.00

BY

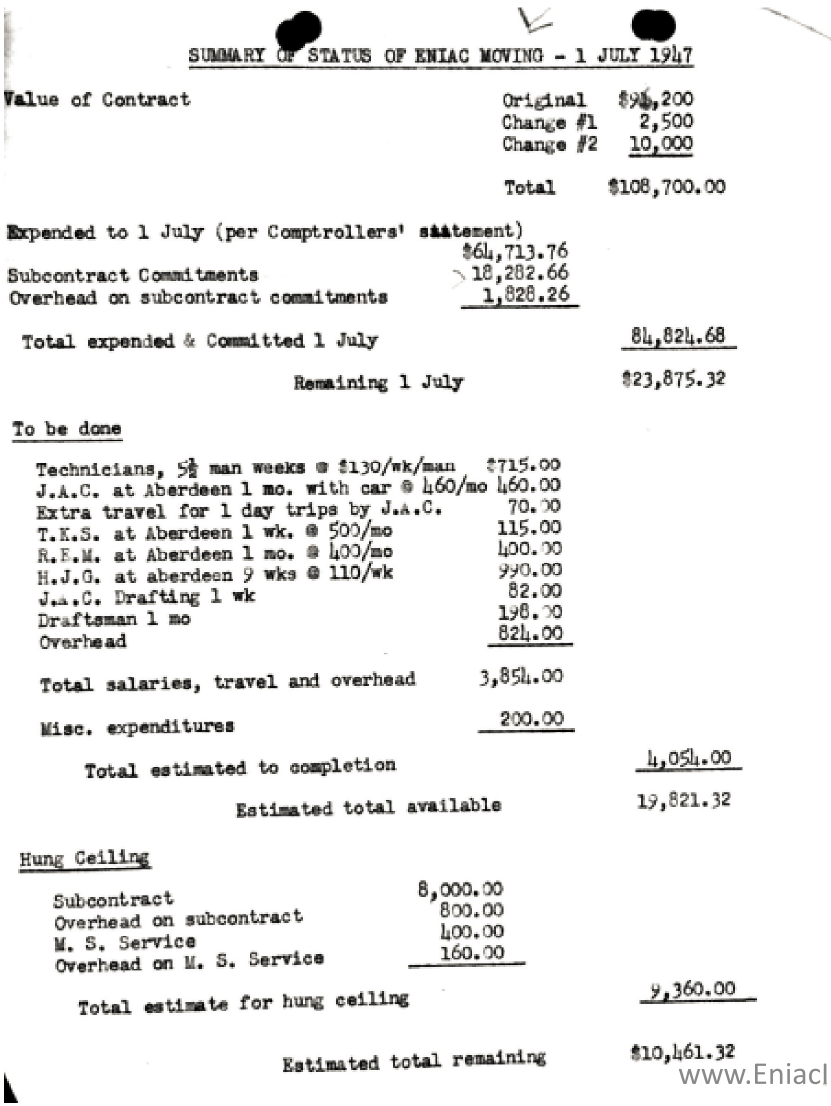
UNITED STATES OF AMERICA

TITLE (Authorized to accept this order) William H. DuBarry, Executive Vice-President

BY A. D. QUINTON, JR. Brigadier General, U.S.A. Commanding, CONTRACTING OFFICER

WD FORM 47

The Move to Aberdeen



SUMMARY OF STATUS OF ENIAC MOVING - 1 JULY 1947

Value of Contract	Original	$96,200
	Change #1	2,500
	Change #2	10,000
	Total	$108,700.00

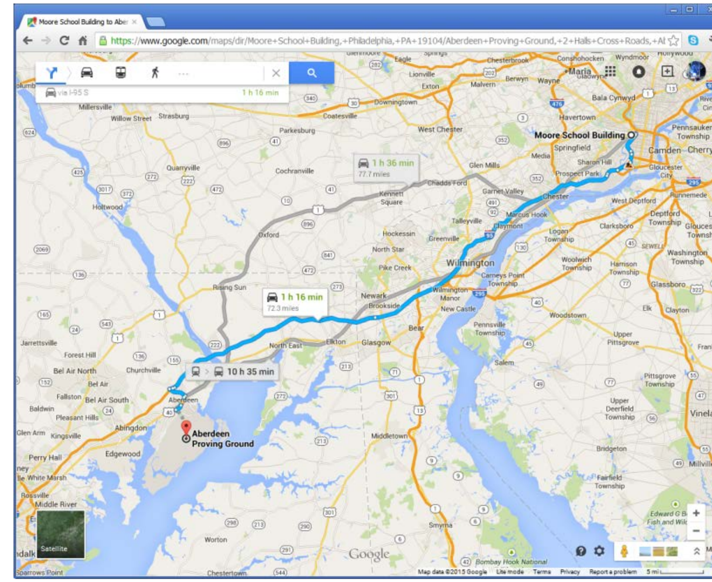
Expended to 1 July (per Comptrollers' statement)	$64,713.76	
Subcontract Commitments	18,282.66	
Overhead on subcontract commitments	1,828.26	
Total expended & Committed 1 July		84,824.68
Remaining 1 July		$23,875.32

To be done

Technicians, 5½ man weeks @ $130/wk/man	$715.00	
J.A.C. at Aberdeen 1 mo. with car @ 460/mo	460.00	
Extra travel for 1 day trips by J.A.C.	70.00	
T.K.S. at Aberdeen 1 wk. @ 500/mo	115.00	
R.F.M. at Aberdeen 1 mo. @ 400/mo	400.00	
H.J.G. at aberdeen 9 wks @ 110/wk	990.00	
J.A.C. Drafting 1 wk	82.00	
Draftsman 1 mo	198.00	
Overhead	824.00	
Total salaries, travel and overhead	3,854.00	
Misc. expenditures	200.00	
Total estimated to completion		4,054.00
Estimated total available		19,821.32

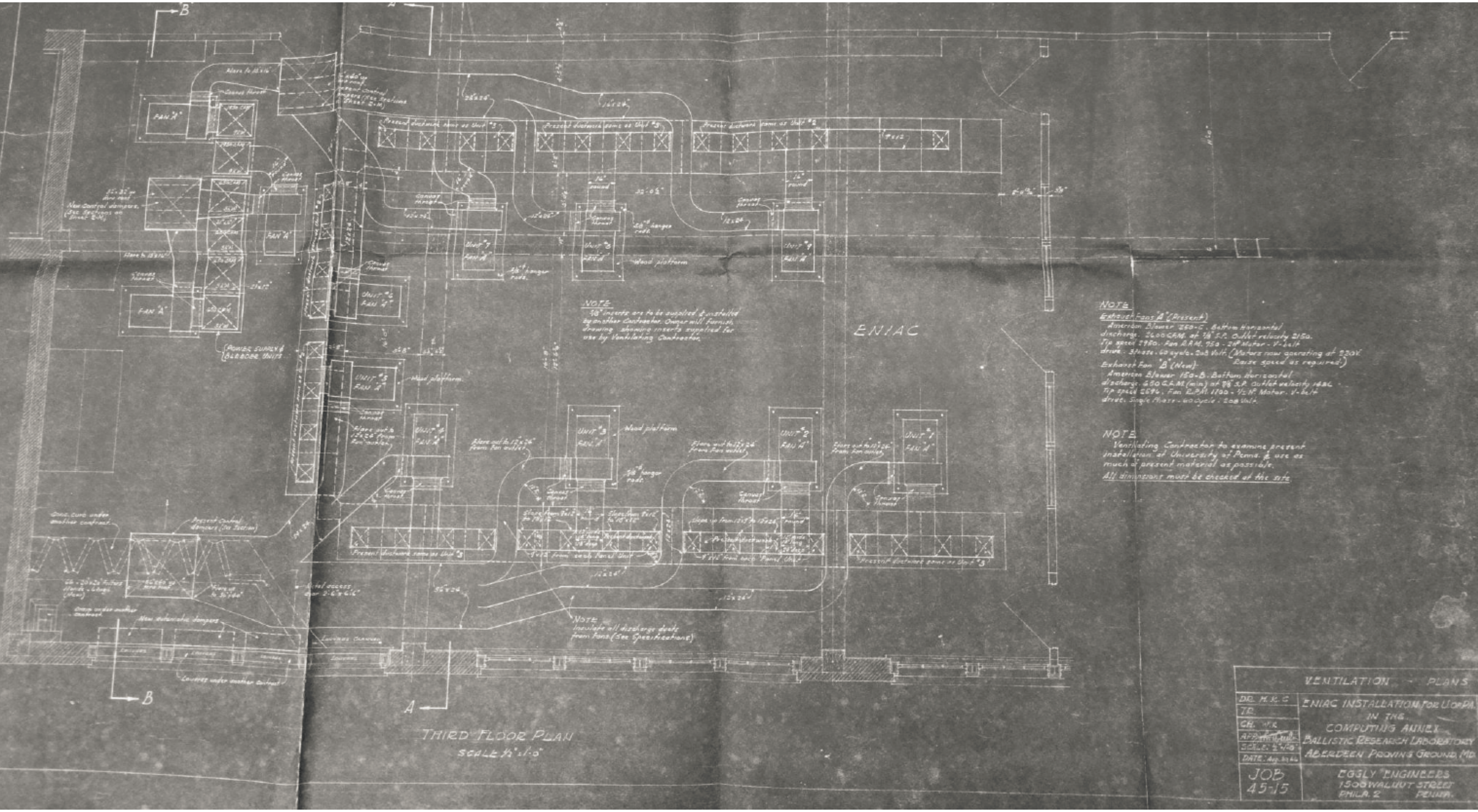
Hung Ceiling

Subcontract	8,000.00	
Overhead on subcontract	800.00	
M. S. Service	400.00	
Overhead on M. S. Service	160.00	
Total estimate for hung ceiling		9,360.00
Estimated total remaining		$10,461.32

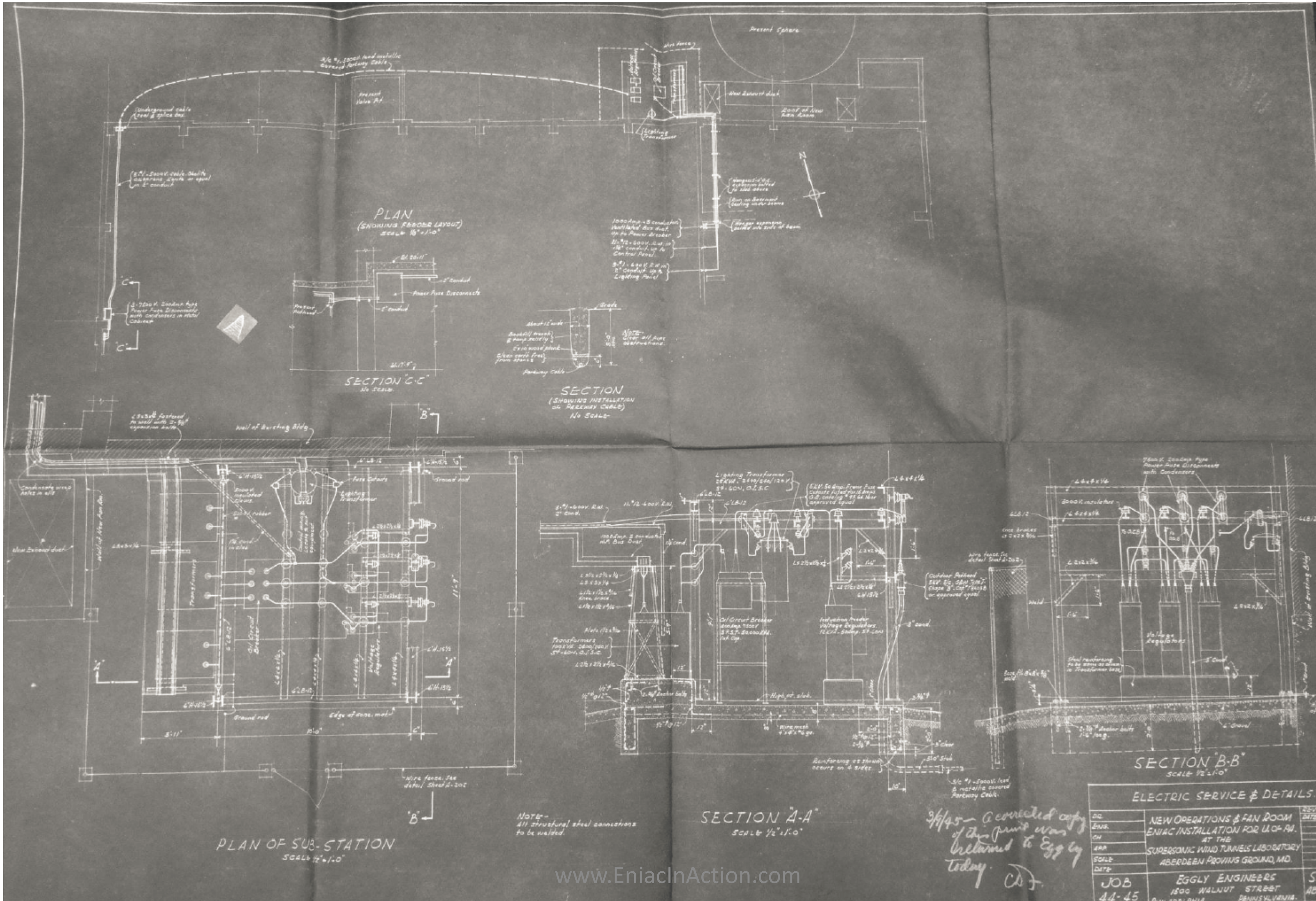


- Contracted to local moving company
- Panels winched through a hole in the outer wall.

Ventilation Plans

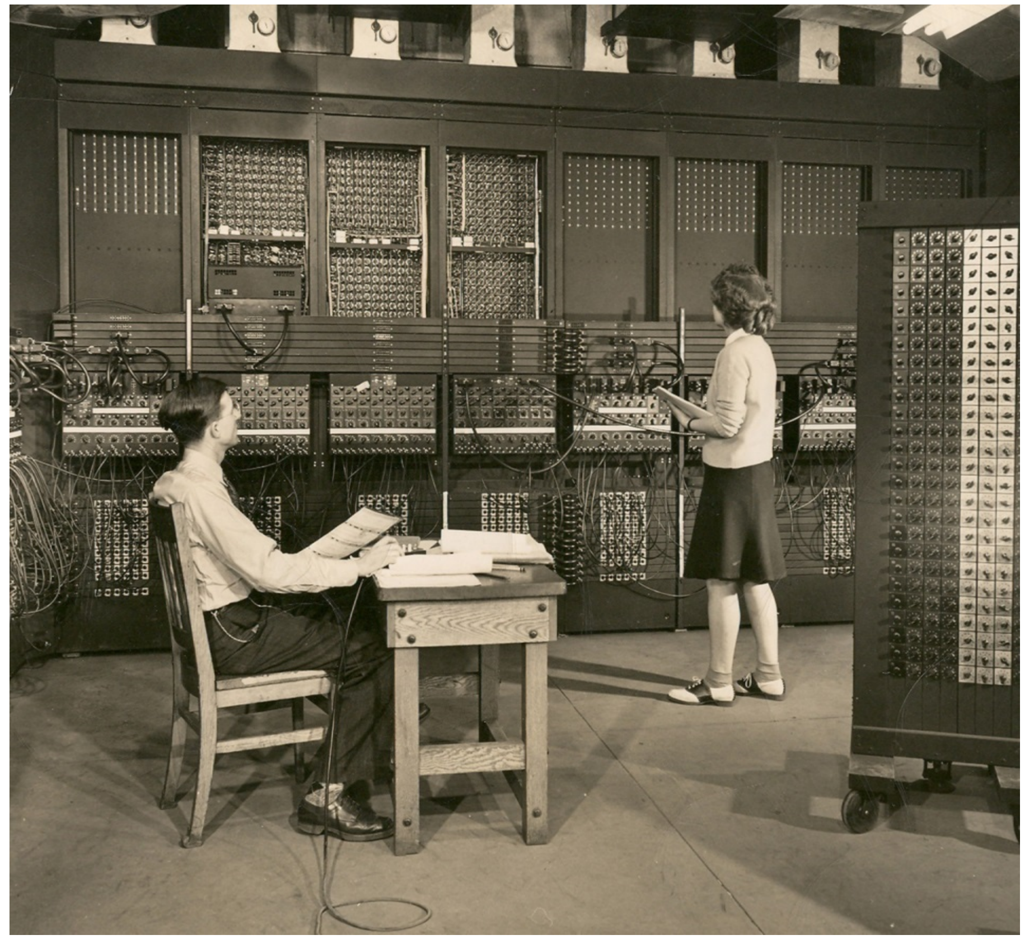


Electric Service Plan

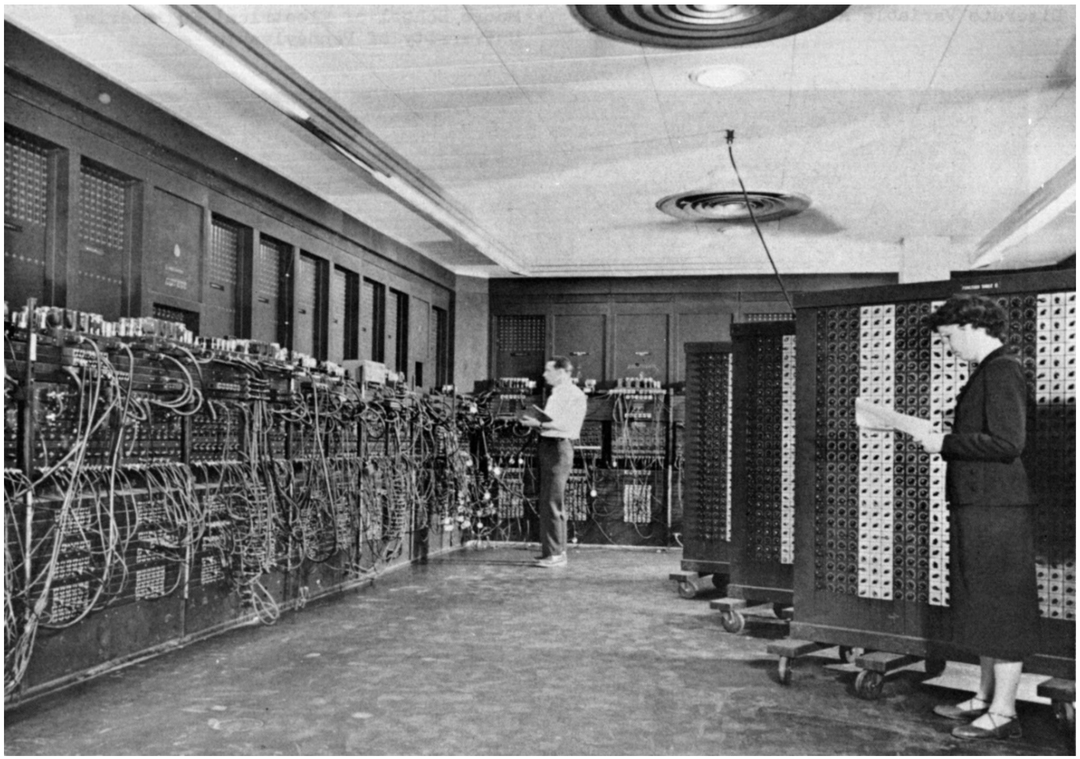


ENIAC Operation

- A hand held unit started/stopped
- Single step mode
- Adjustable clock speed



The Suspended Ceiling



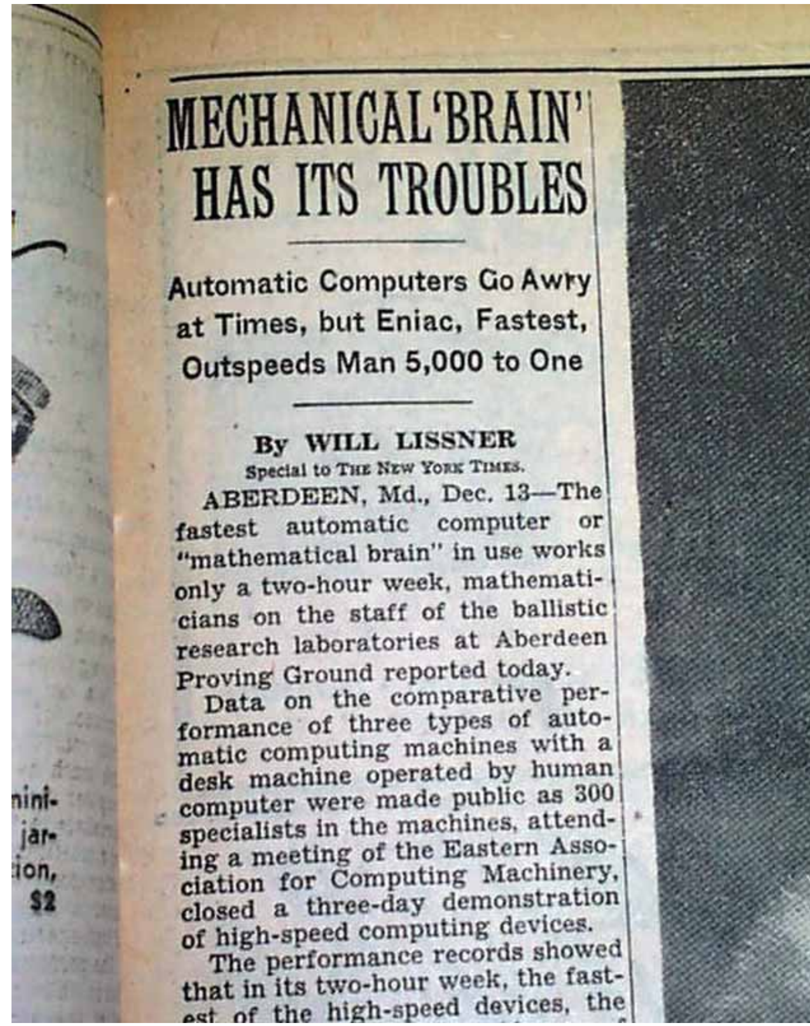
- Proposed in early planning, but seen as luxury
- Approved by the Army only in June, 1947
  - Installed 1948

ENIAC as a Showpiece

- Even before ENIAC was finished, there were enough visitors to trigger a ban
- In 1948, regular visits by delegations for demonstrations

In December 1947

- Running on production work 2 hours a week!
- 17% of time setting up and testing configurations
- 49% checking, diagnosing, and fixing hardware



MECHANICAL 'BRAIN' HAS ITS TROUBLES

Automatic Computers Go Awry at Times, but Eniac, Fastest, Outspeeds Man 5,000 to One

By WILL LISSNER

Special to THE NEW YORK TIMES.

ABERDEEN, Md., Dec. 13—The fastest automatic computer or "mathematical brain" in use works only a two-hour week, mathematicians on the staff of the ballistic research laboratories at Aberdeen Proving Ground reported today.

Data on the comparative performance of three types of automatic computing machines with a desk machine operated by human computer were made public as 300 specialists in the machines, attending a meeting of the Eastern Association for Computing Machinery, closed a three-day demonstration of high-speed computing devices.

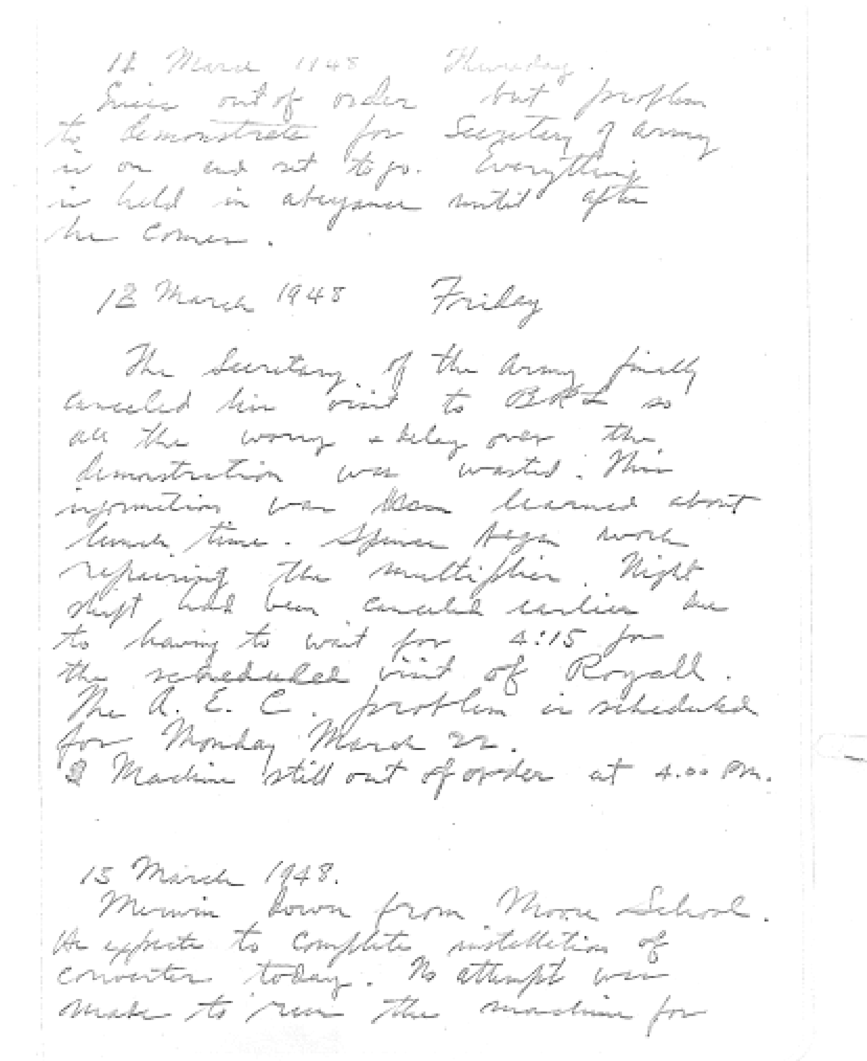
The performance records showed that in its two-hour week, the fastest of the high-speed devices, the

Struggling for Reliability

- Frank E. Grubbs, Ph.D. student turned mathematical analyst for BRL
  - Pioneered statistical tests for outliers
- Three weeks of computer time before first useful output produced
  - Intermittents
  - Power supplies “dumping”
  - Error in mathematical treatment
  - Time lost to hardware upgrades
  - Unreproducible results
  - Preparations for inspection by Secretary of Army

ENIAC Operations Log

- Preserved, but never used by historians previously


11 March 1948 Thursday.
Eniac out of order but problem
to demonstrate for Secretary of Army
is on and set to go. Everything
is held in abeyance until after
he comes.

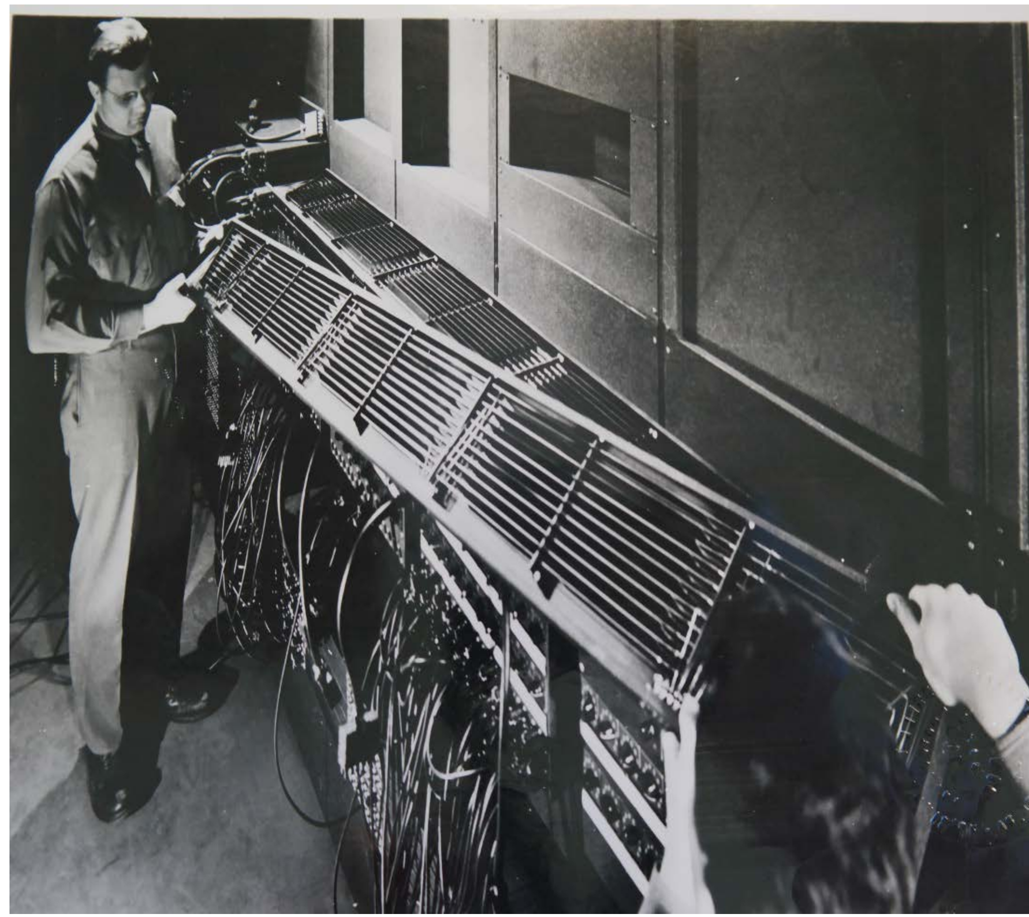
12 March 1948 Friday

The Secretary of the Army finally
cancelled his visit to BRL so
all the worry + delay over the
demonstration was wasted. This
information was soon learned about
lunch time. Spence Hogan work
repairing the multiplier. Night
shift had been cancelled earlier due
to having to wait for 4:15 for
the scheduled visit of Royall.
The A. E. C. problem is scheduled
for Monday March 22.
Machine still out of order at 4.00 PM.

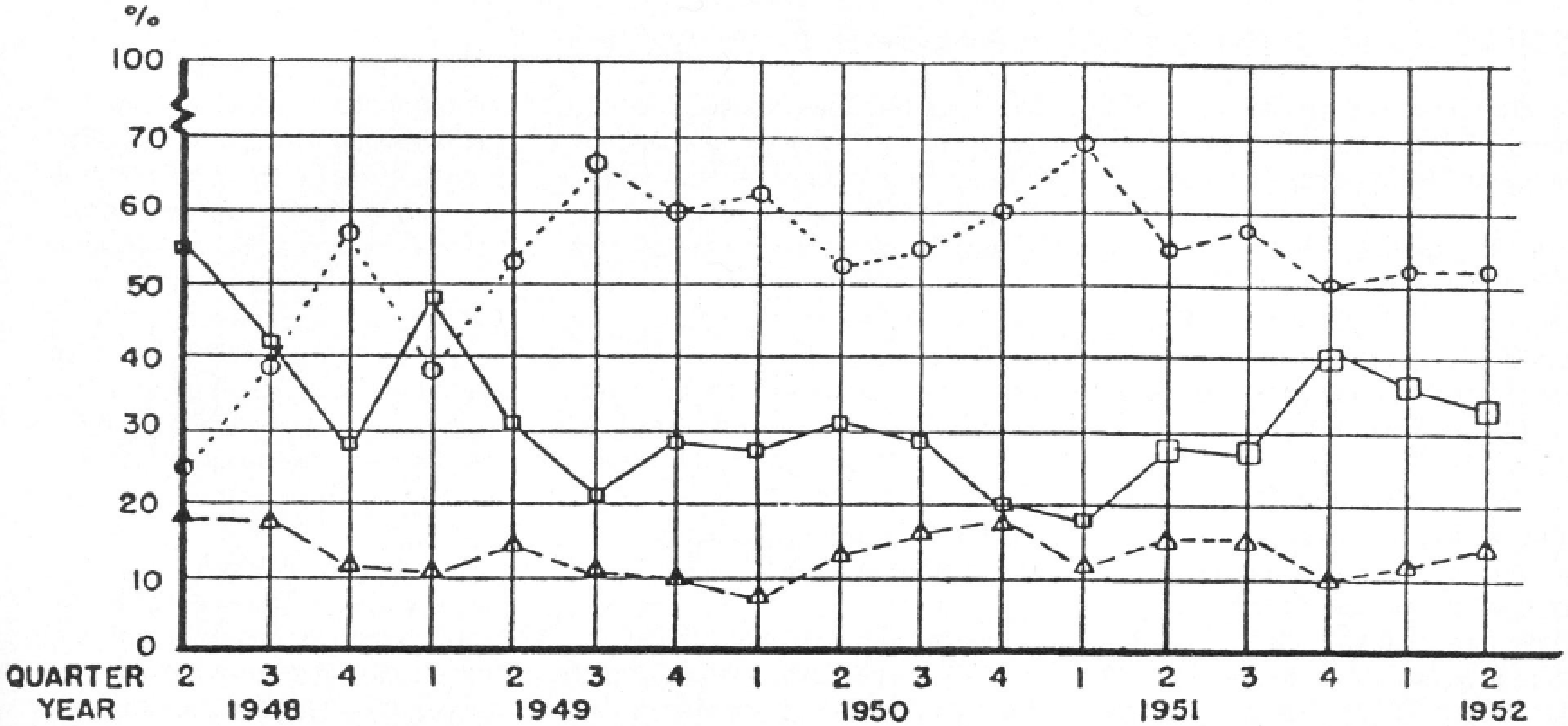
15 March 1948.
Merwin down from Moore School.
He expects to complete installation of
converter today. No attempt was
made to run the machine for

Homer Spence

- Original an army technical assigned to ENIAC
- Returned to BRL as civilian employee
- Spence "detected so many cold solder joints that he simply went through and resoldered every joint on the machine."



Usable Machine Time

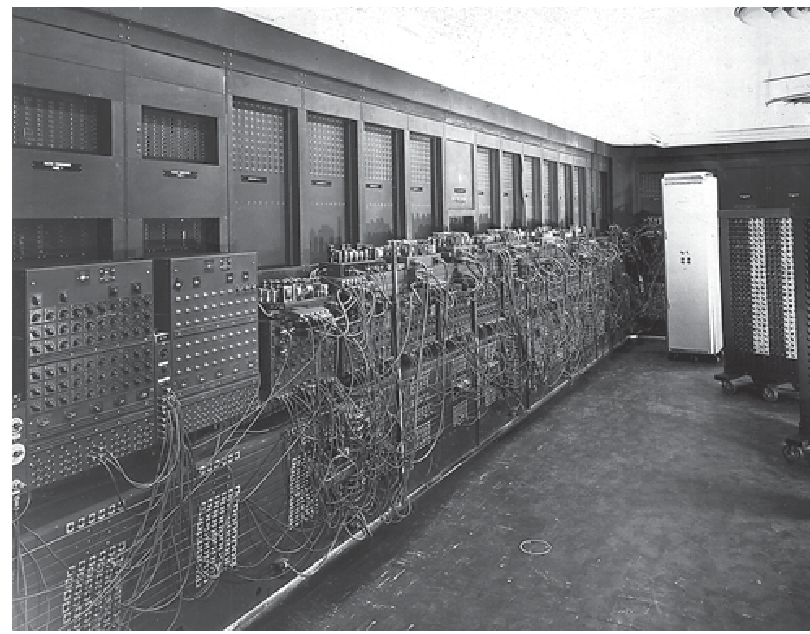


1. O----O CORRECTLY OPERATING ON THE SOLUTION OF REGULAR PROBLEMS.
2. □——□ LOCATING AND CORRECTING MACHINE TROUBLE IN THE ENIAC, NON DUPLICATION TIME, AND DOWN TIME ON SPECIAL PREVENTIVE MAINTENANCE.
3. Δ----Δ PLACING NEW PROBLEMS ON THE ENIAC, CHECKING PROGRAMMING, DATA ANALYSIS, AND DOWN TIME DUE TO HUMAN OPERATING ERROR.

REMAKING ENIAC

Core Memory

- ENIAC’s biggest limitation was its tiny writable electronic memory
- “Register” delay line memory ordered 1947. Delivered, but never worked.
- Random access static core memory delivered by Burroughs corporation 1953



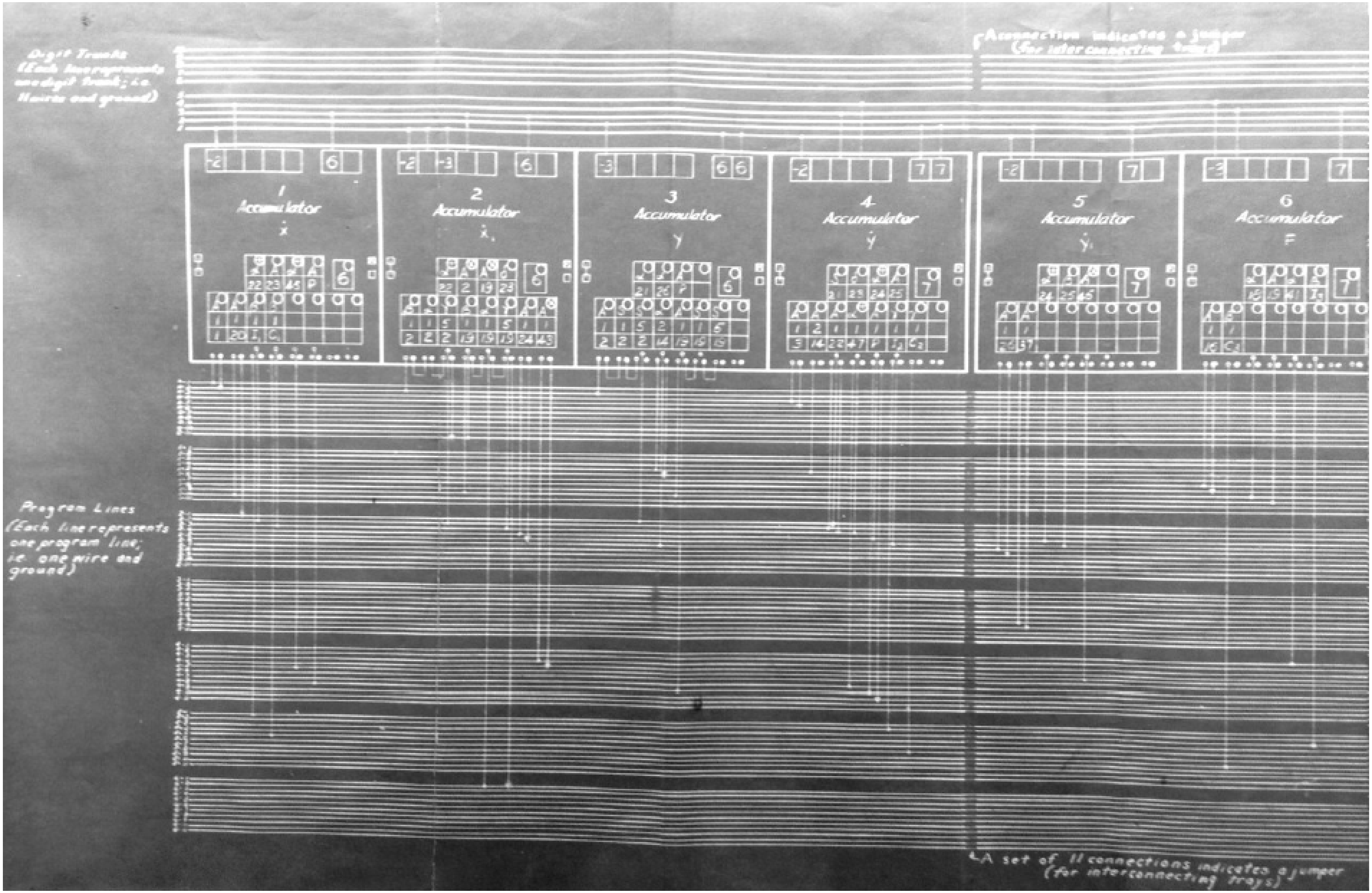
Biggest changes concerned programming

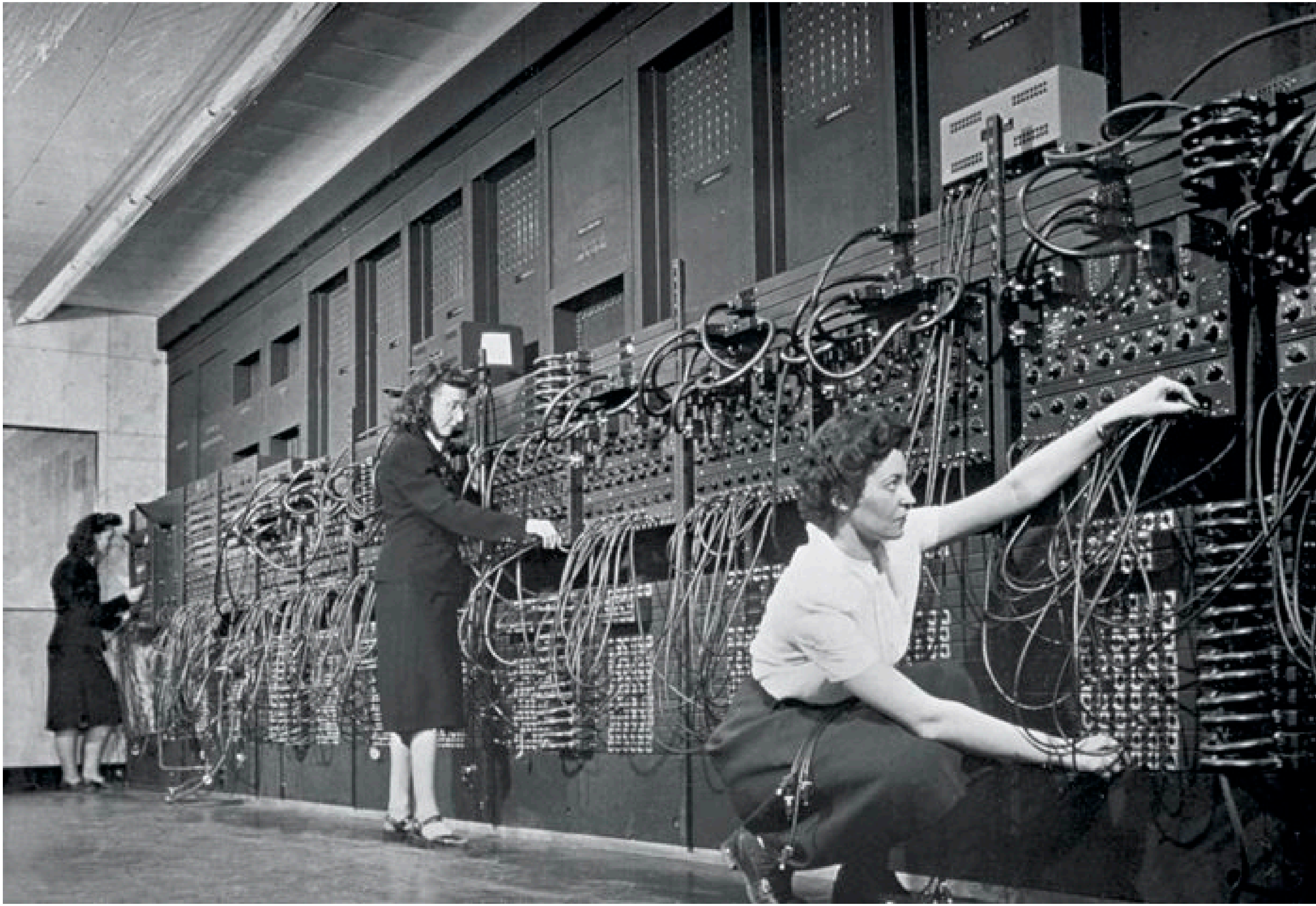
- Traditional system started with step by step chart of operations over time

Step (Initiated by master programmer Consists of several operations)	Serial Order Number of Operation	Addition Times Required	Program Line Used	1	2	3	4
	Number of Unit of ENIAC			1	2	3	4
		Setting of Accumulator Round-off Switch		6	6	6	7
		Decimal Point of Accumulator		3.7	3.7	4.6	3.7
				Accumulator $\dot{x}$ $0<x<10^3$	Accumulator $\dot{x}_1$	Accumulator y $0<y<10^4$	Accumulator $\dot{y}$ $0<\dot{y}<10$
Initial Conditions Step	I_1	1	5-1	$\dot{x}_i$ ←			
	I_2	1	5-2				$\dot{y}_i$ ←
	I_3	1	5-3				
			5-4				
	1	1	0-1	$\dot{x}_0$ [3.3]			
	2	9	0-2		$10^{-1}y_0$ [3.3] ← $\boxed{-2}$ ←	S y_0 [4.2]	
			0-11		$10^{4}by_0$ [3.4] $\boxed{-3}$ ←	S	
	3	1	0-3				$\dot{y}_0$ [3.4]
	4	10	0-4				
	5	1	0-5				

Composition: Laminar boundary layer, Zero order Equations. Schedule for integration procedure.

M.P.	Acc 1	Acc 2	Divider	Acc 3	Acc 4	Acc 5	Acc 6	Acc 7	Acc 8	Acc 9	Acc 10	HSM	Acc 11	Acc 12	Acc 13	Acc 14	Acc 15	Acc 16	Acc 17	Acc 18	FT 3	Acc 19	Acc 20	C.T.
	H(0)	Quotient		Numerator	r(0)	Denominator		Divider shifter		ico	icand		LHPP		RHPP		H	h	R	r	4-digit	f′	F	
Digit Ctrs, Shifter, Deleter																								
	H(0)				r(0)					0	0	0	0	0	0	0	H_0	h_0	R_0	r_0		f'_0	F_0	
Pulses from M.P. to initiating integration sequence → A-1										F_0	H_0	αc αo sc1					AO	α1					AO	
										H_0	H_0	βc αc AC1			F_0H_0		AO	α1						
										F_0	R_0	αc αc AC			H_0^2	α1 H_0^2		h_1	AO				AO	
											β01 F_0R_0				F_0R_0				SO	α0				
										γ0	γ01					AC								0.75
										r	$F_0R_0 - 0.1H_0^2$	αc αc AC												
															$r(F_0R_0-0.1H_0^2)$	γ05 n α1				α0 ($2r_1$)					
														γ0n		ACn				AO5				
																α02 $H_1^2 r_1$						Input		
																A01 Σ	α02							1.
A1																						output w_0 after 4 stabilization		
B1																								
														α01 w_0	α01 w_0									
										w_0	w_0	αo βc AC			AC w_0^2									
										w_0	w_0	αc βc AO			w_0^3									


Digit Trunks (Each line represents one digit trunk; i.e. 11 wires and ground)
A connection indicates a jumper (for interconnecting trays)
1 Accumulator
2 Accumulator
3 Accumulator
4 Accumulator
5 Accumulator
6 Accumulator
F
Program Lines (Each line represents one program line; i.e. one wire and ground)
A set of 11 connections indicates a jumper (for interconnecting trays)



First Draft of a Report on the EDVAC

by

John von Neumann

Contract No. W-670-ORD-4926

Between the

United States Army Ordnance Department

and the

University of Pennsylvania

Moore School of Electrical Engineering
University of Pennsylvania

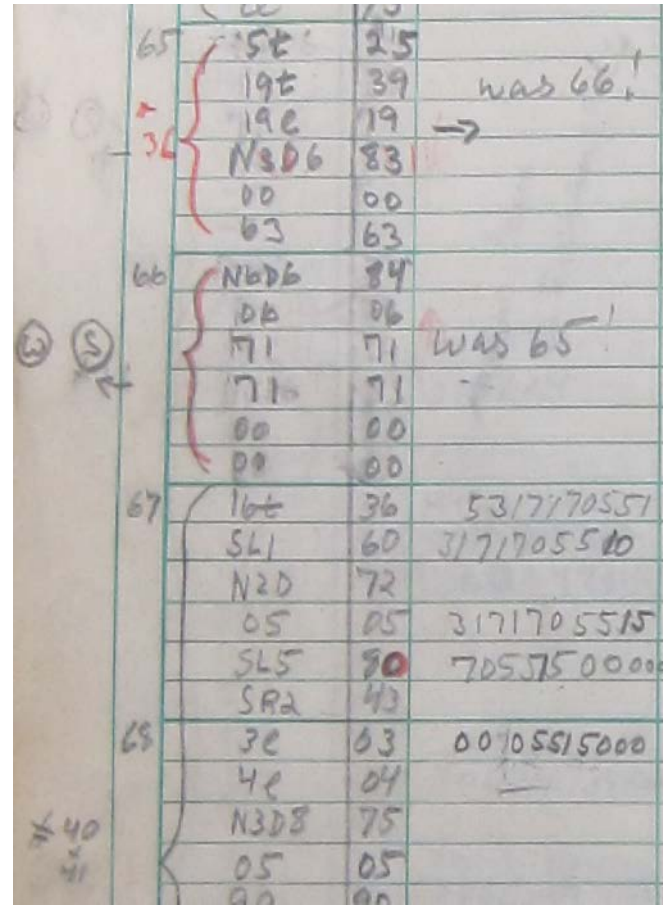
June 30, 1945

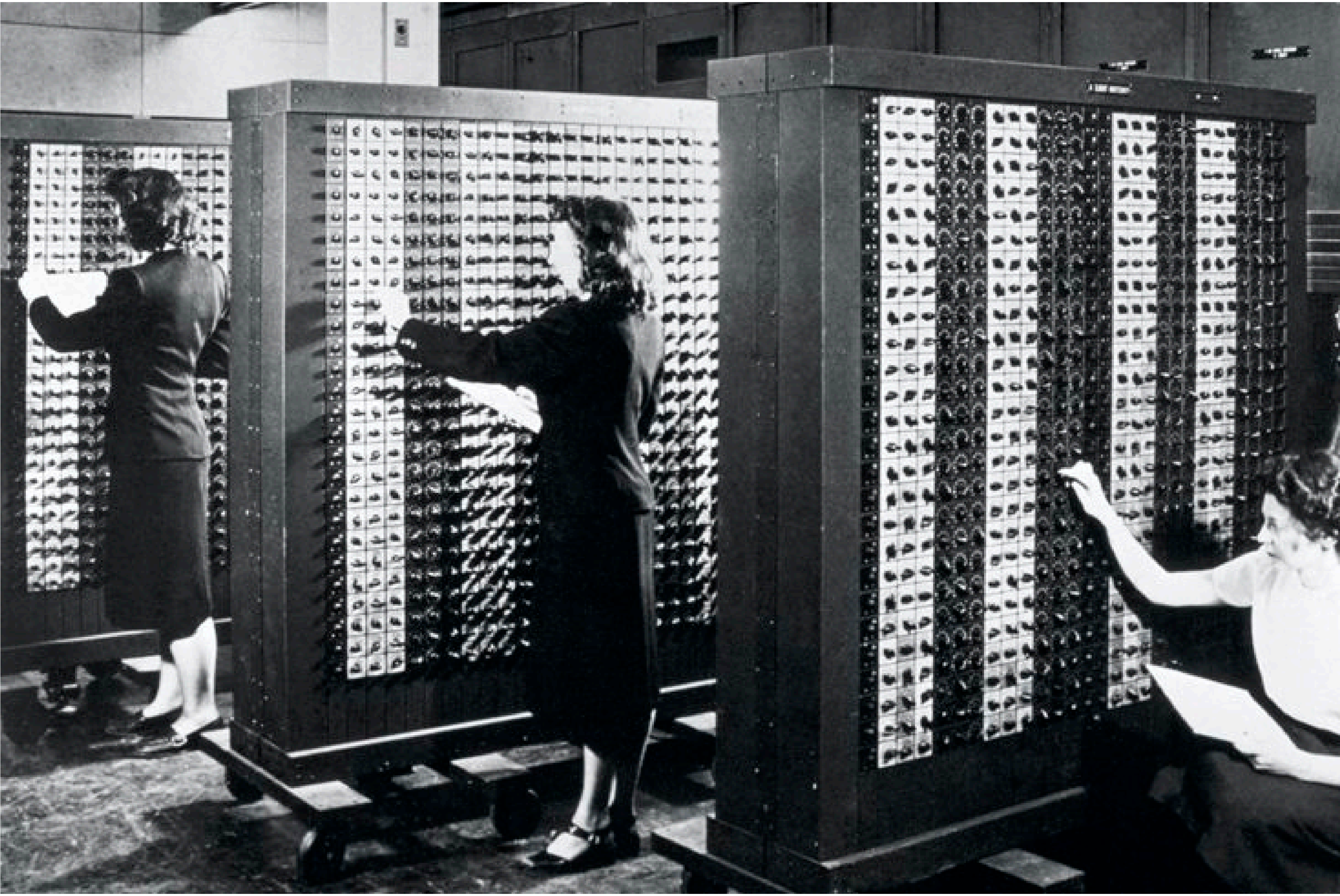
Table.

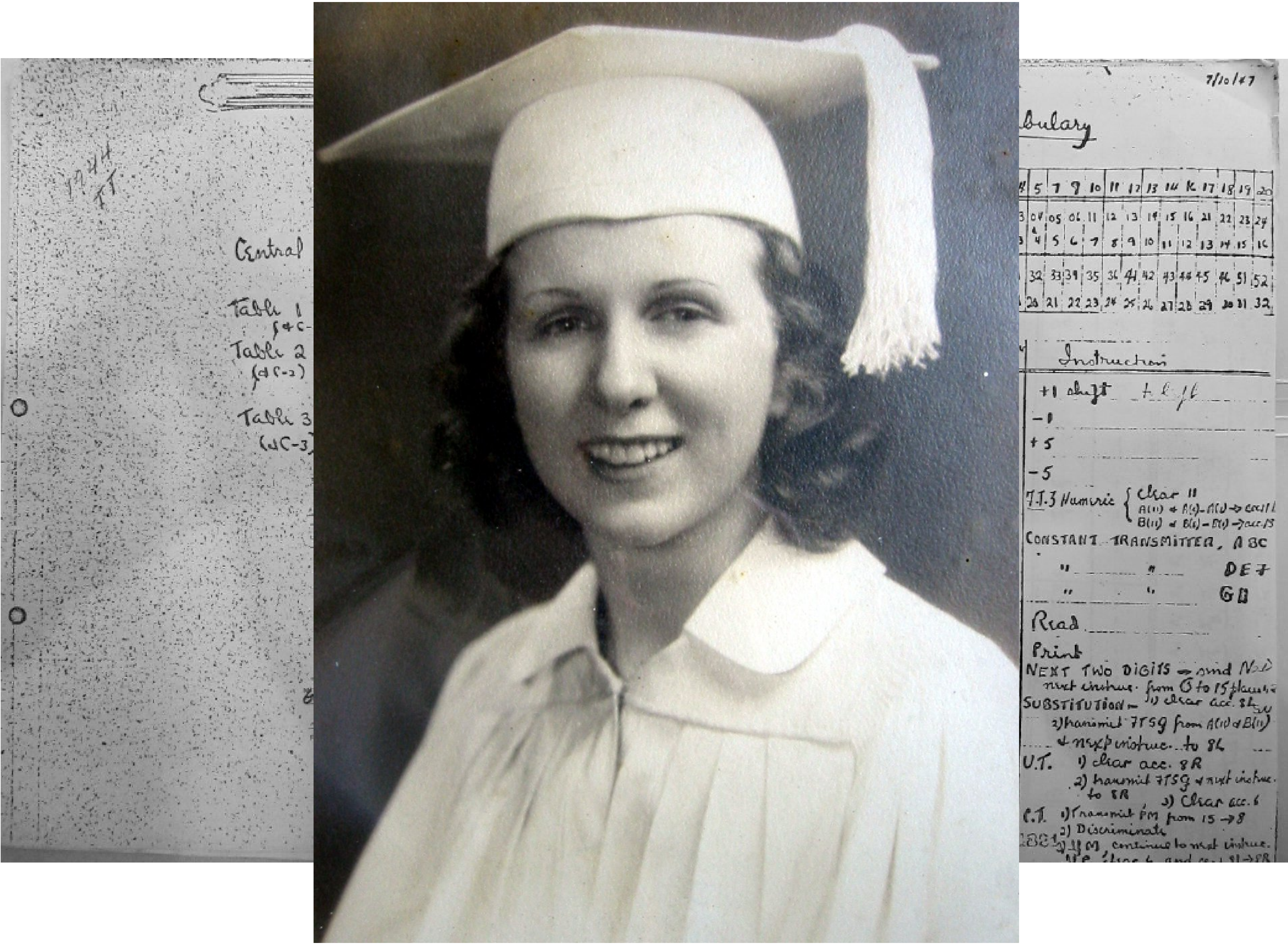
<table>
<tr><th>(I)
Type.</th><th>(II)
Meaning.</th><th>(III)
Short Symbol</th><th>(IV)
Code Symbol</th></tr>
<tr><td></td><td></td><td></td><td>Minor cycle
$I = (i_\nu) = (i_0 i_1 i_2 \cdots i_{31})$</td></tr>
<tr><td>Standard number or Order (γ)</td><td>Storage for the number defined by $\xi = i_{31} \cdot i_{30}\, i_{29} \cdots i_1 = \sum_{\nu=1}^{31} i_\nu 2^{31-\nu}$ (mod 2), $-1 \leq \xi < 1$.
i_{31} is the sign: 0 for +, 1 for −.
If CC is connected to this minor cycle, then it operates as an order, causing the transfer of into I_{ca}. This does not apply however if this minor cycle follows immediately upon an order $w \to A$ or $wh \to A$.</td><td>$N\xi$</td><td>$i_0 = 0$</td></tr>
<tr><td>Order $(\alpha)+(\bar{\delta})$</td><td rowspan="4">Order to carry out the operation w in CA and to dispose of the result. w is from the list of 11.4. These are the operations of 11.4, with their current numbers w and their symbols w:
<table>
<tr><th>w, decimal</th><th>w, binary</th><th>w</th><th>w, decimal</th><th>w, binary</th><th>w</th></tr>
<tr><td>0</td><td>0000</td><td>+</td><td>5</td><td>0101</td><td>i</td></tr>
<tr><td>1</td><td>0001</td><td>−</td><td>6</td><td>0110</td><td>j</td></tr>
<tr><td>2</td><td>0010</td><td>x</td><td>7</td><td>0111</td><td>s</td></tr>
<tr><td>3</td><td>0011</td><td>÷</td><td>8</td><td>1000</td><td>db</td></tr>
<tr><td>4</td><td>0100</td><td>√</td><td>9</td><td>1001</td><td>bd</td></tr>
</table>
h means that the result is to be held in O_{ca}. →up means, that the result is to be transferred into the minor cycle ρ in the major cycle u; →f, that it is to be transferred into the minor cycle immediately following upon the order; →A, that it is to be transferred into I_{ca}; no →, that no disposal is wanted (apart from h).</td><td>w→up
or
wh→up</td><td>$i_1 = 1$</td></tr>
<tr><td>Order $(\alpha)+(\epsilon)$</td><td>w→f
or
wh→f</td><td></td></tr>
<tr><td>Order $(\alpha)+(\delta)$</td><td>w→A
or
wh→A</td><td></td></tr>
<tr><td>Order (α)</td><td>wh</td><td></td></tr>
<tr><td>Order (β)</td><td>Order to transfer the number in the minor cycle in the major cycle u into I_{ca}.</td><td>A←up</td><td></td></tr>
<tr><td>Order</td><td>Order to connect CC with the minor cycle in the major cycle u.</td><td>C←up</td><td></td></tr>
</table>

New Programming System

- Inspired by 1945 “First Draft of a Report on the EDVAC” by John von Neumann
- From March 1948 ENIAC control switches and wires no longer moved
- Programs were written as numerical codes read and executed from addressable memory
- First modern computer program ever run!






7/10/47
Central
Table 1
Table 2
Table 3
Instruction
CONSTANT TRANSMITTER, ABC
Read
Print
NEXT TWO DIGITS
SUBSTITUTION
Discriminate

Moore School Programming Group

- Set up March 1947 here, under contract to BRL
  - First leader was Jean Bartik, who didn't want to leave Philadelphia with ENIAC
  - Worked on applications and on "converter code"
  - Probably the first time anyone was hired specifically to do programming

November 7, 1947

Initiating

P_i	O-1
P_o	C-5
R_i	O-2
R_o	C-5
Sc_i #1	F-5
Sc_o #1	G-8
Sc_i #2	E-3
Sc_o #2	U-10
Sc_i #3	O-4
Sc_o #3	C-4

ter Programmer

pper A

B-2		
E-2		
F-5		
C-1	St. 4	S-3
S-1	St. 5	S-4
S-2	St. 6	S-5

pper B

B-5

E-2

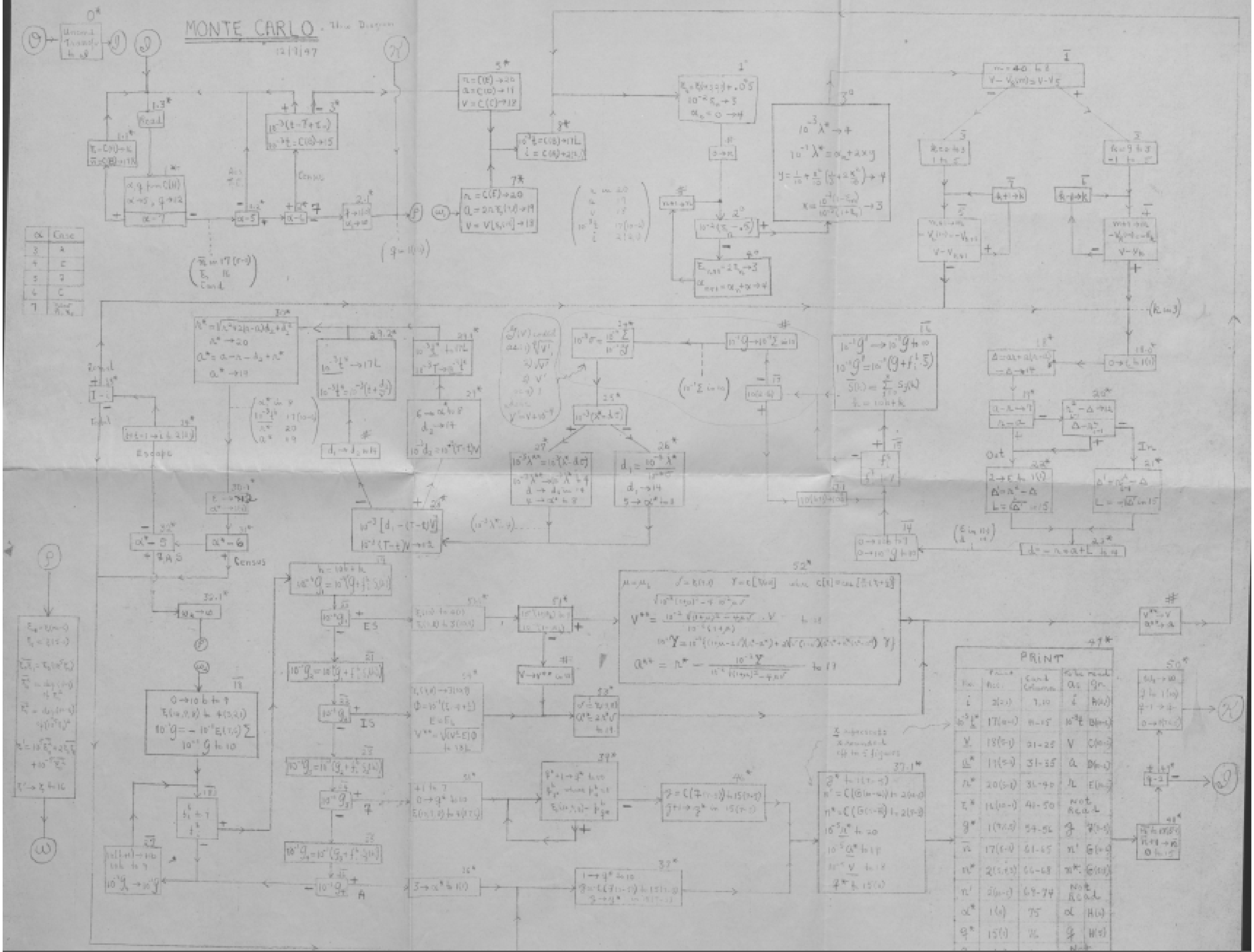
BASIC SEQUENCE
F.T. CONTROL
SHEET 1 OF 1

1

D-1 → C-2
D-1 → E-1

E-8 → F-1 → F-3

IU	MP	2	3	6	10	20	CONV	OS	FT	FTS
IP D-1										
		D-1 001 $\boxed{C-5}$						C-2 cold		E-1 im (C2)
$\boxed{C-5}$ 001 $\boxed{E-8}$										
F-1 001						$\boxed{E-8}$ 004			H-1 ... 6	F-3 i...



MONTE CARLO
Read
Census
Escape
PRINT

171	le	15	
	16t	36	
	SlR1	38	
	12t	62	
	SlL5	86	
	11e	11	
172	L12t	62	
	11le	10	67900 98765
	le	15	
	11le	15	567900 9876
	le	15	09876
	le	15	
173	12t	62	
	SL5	80	
	x	57	0560858040
	7e	07	
	11t	31	
	x	57	0097535376
174	SR5	52	00975
	7t	27	0560859015
	7t	27	1121717055
	7e	07	
	12t 10e	62 80	
	SL5	80	
175	11e	11	
	11t	31	
	x	57	3225104100
	SL5	80	04100
	7t	27	
	DS	46	1531717055
176	S'-40	O	5317170550
	12t	62	5317170551
	16e	16	
	Count		
	CT	69	

9

6

le
16t
SR1

CONCLUSIONS

Female Pioneers

- Underrepresentation of women in IT has inspired a hunt for female role models and pioneers
- Historical figures become figureheads for events
  - Ada Lovelace (Day)
  - Grace Hopper (Celebration of Women in Computing) ----- >>
  - The "women of ENIAC" increasingly celebrated as "the first programmers"
  - Proof that women can program

“The Women of ENIAC”

- (We explore the history of ENIAC in popular and scholarly memory)
- Title of 1996 article by W. Barkley Fritz
  - Fragments of memoirs from many women who worked on ENIAC
- Kathy Kleiman works for decades on a film, bringing more attention
  - Esp. 1996 a 1996 WSJ column by Tom Petzinger
- Jennifer S. Light 1999 paper “When Computers Were Women”

Misremembering History

Groundbreaking for "Pennovation Center" Oct, 2014:

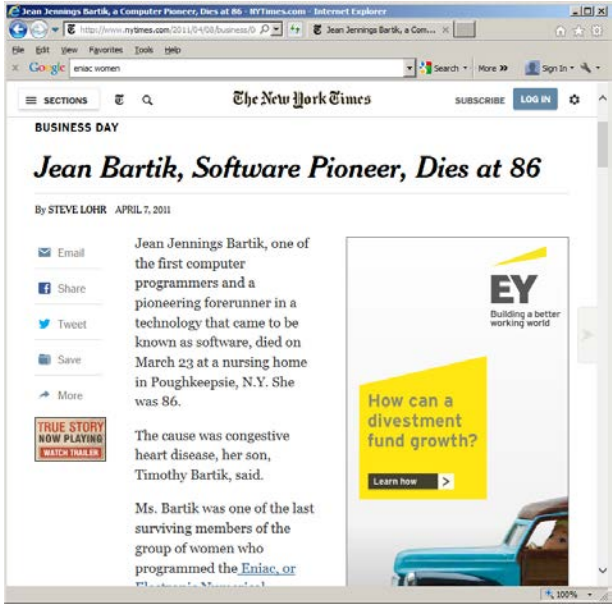
"Six women Ph.D. students were tasked with programming the machine, but when the computer was unveiled to the public on Valentine's Day of 1946..."

(Report on the Penn website).

Erasing Women's Contributions

- "Women of ENIAC" = the first six operators
  - Not the women who built ENIAC
  - Or Adele Goldstine who wrote the manual and trained & recruited other women
  - Or Klara von Neumann, who coded the first modern program ever run
  - Or the many later operators and programmers at BRL

Famous for being forgotten?



BUSINESS DAY

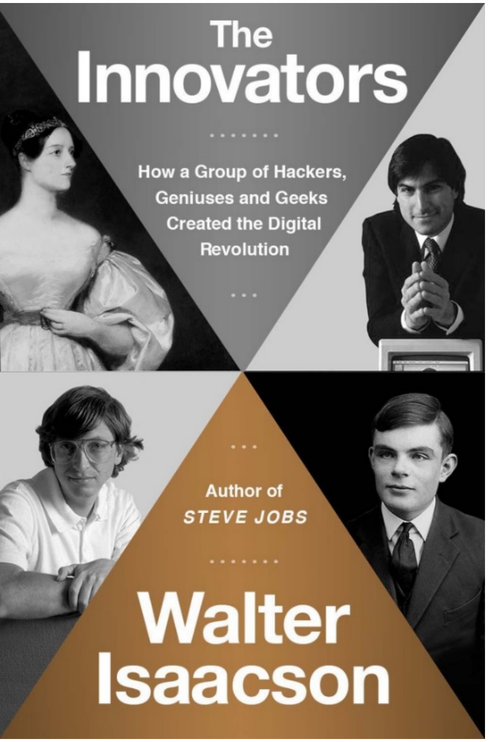
Jean Bartik, Software Pioneer, Dies at 86

By STEVE LOHR APRIL 7, 2011

Jean Jennings Bartik, one of the first computer programmers and a pioneering forerunner in a technology that came to be known as software, died on March 23 at a nursing home in Poughkeepsie, N.Y. She was 86.

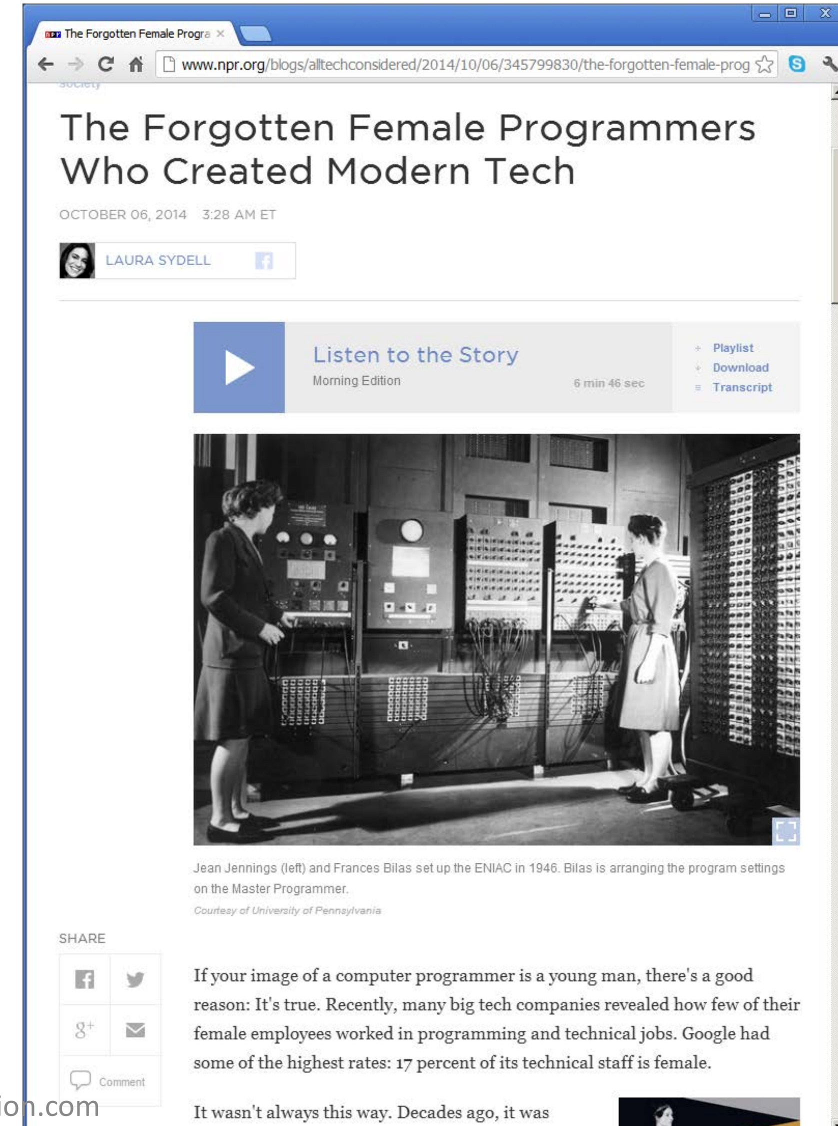
The cause was congestive heart disease, her son, Timothy Bartik, said.

Ms. Bartik was one of the last surviving members of the group of women who programmed the Eniac, or



Walter Isaacson (2014)

- “All the engineers who built ENIAC’s hardware were men…”
- “all the programmers who created the first general-purpose computer were women.”



The Forgotten Female Programmers Who Created Modern Tech

OCTOBER 06, 2014 3:28 AM ET

LAURA SYDELL

Listen to the Story
Morning Edition
6 min 46 sec
Playlist
Download
Transcript

Jean Jennings (left) and Frances Bilas set up the ENIAC in 1946. Bilas is arranging the program settings on the Master Programmer.

Courtesy of University of Pennsylvania

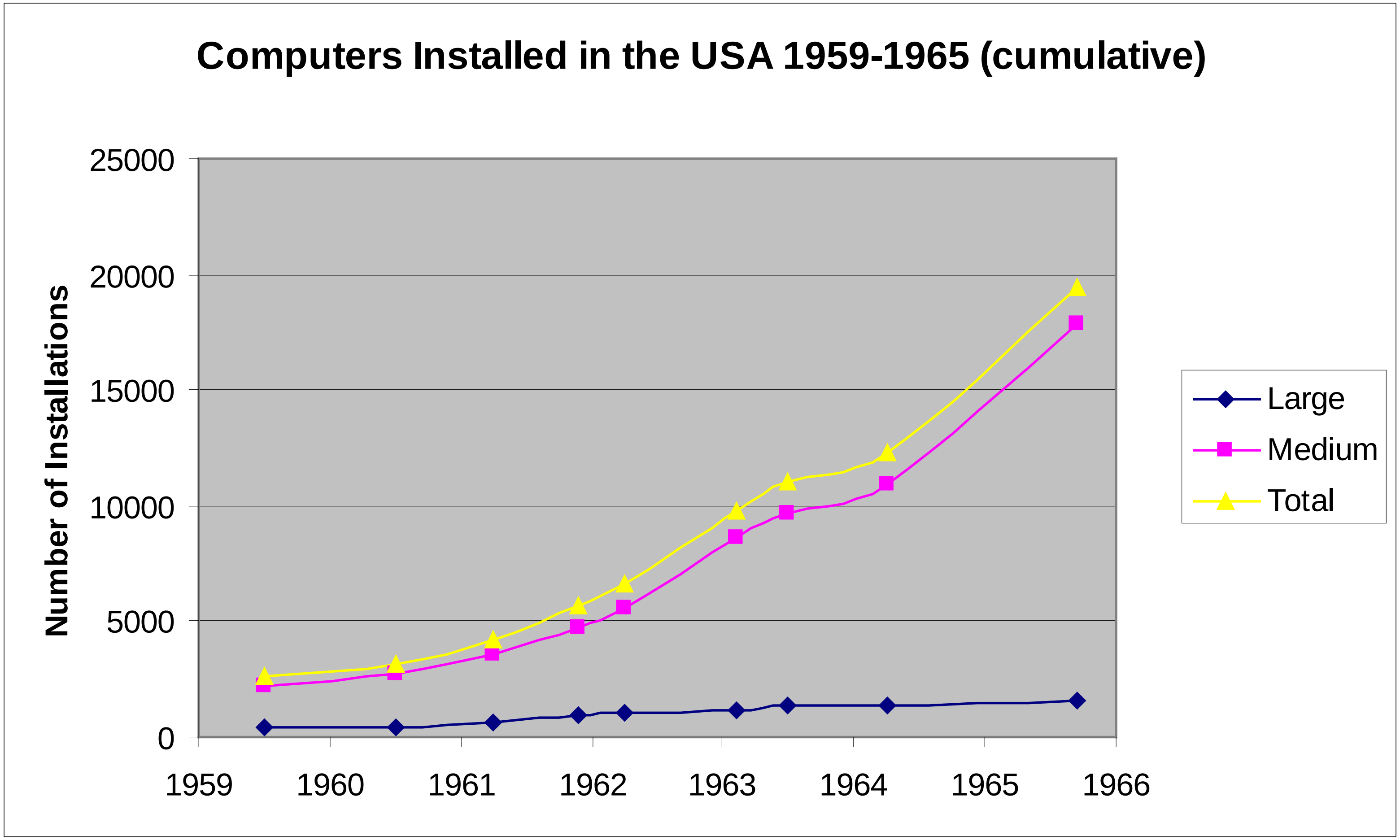
SHARE

Comment

If your image of a computer programmer is a young man, there's a good reason: It's true. Recently, many big tech companies revealed how few of their female employees worked in programming and technical jobs. Google had some of the highest rates: 17 percent of its technical staff is female.

It wasn't always this way. Decades ago, it was

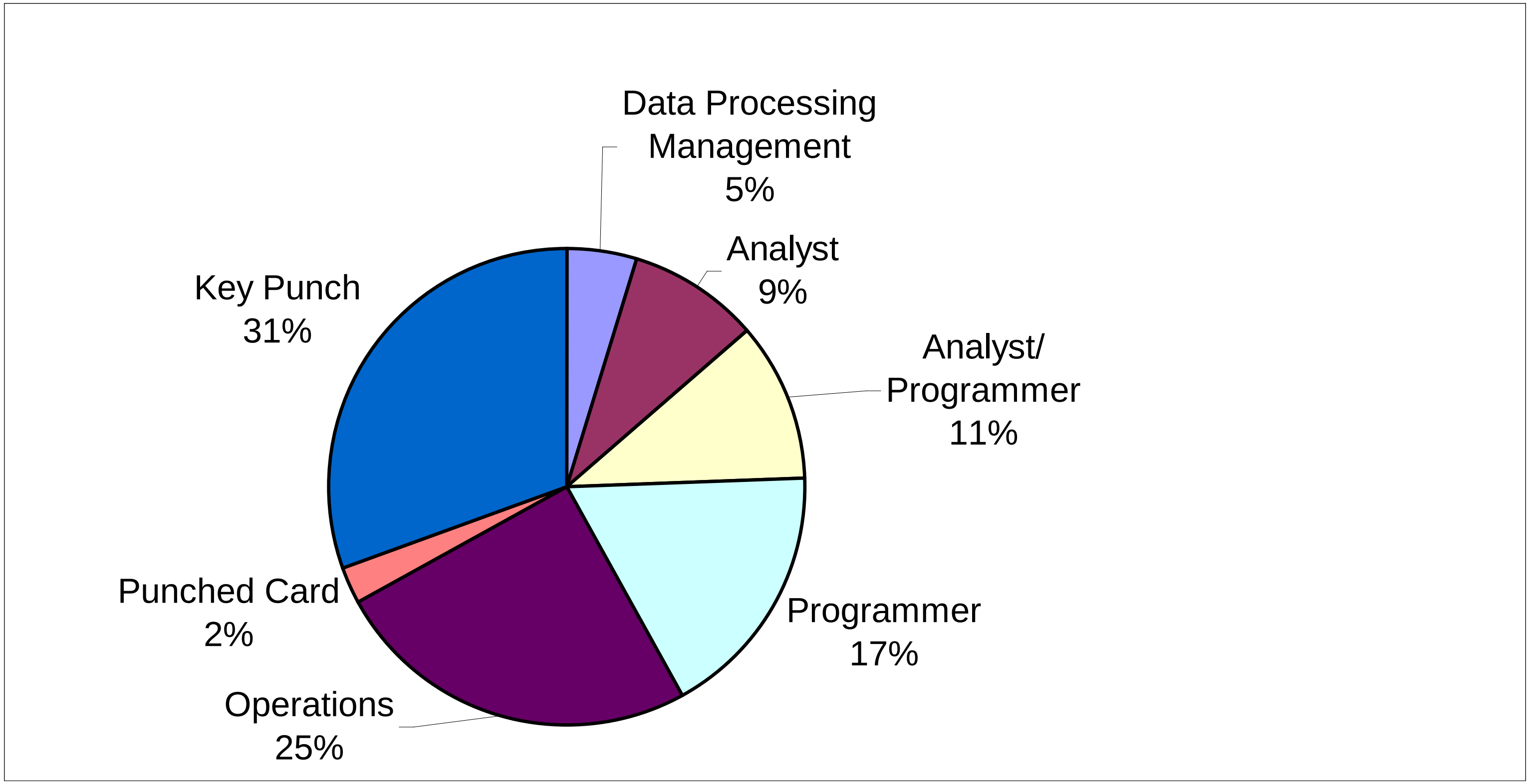
The Computer Enters Business



In 1959 there are 45,000 punched card installations.

In 1962, IBM revenue from computer products overtakes that from punched card products

Data Processing Staff, 1971



Women Who Operate

- We can't fix the "Great Man" view of history by adding a few "Great Women"
  - Insistence on genius and innovative breakthroughs
- By 1950s, computer operations and keypunch work seen as almost blue collar
  - Also the computer work most likely to be done by women
- "reclaiming these women as the first programmers…glosses over the hierarchies…among operators, coders, and analysts."
  (Wendy Hui Kyong Chun)

“Innovation” Associated With

- Science, Progress, the Future
  - Silicon Valley
  - Billionaires
- History, by definition, is about the past
- Famous Silicon Valley venture capitalist Vinod Kholsa stated not long ago…

  > If subjects like history and literature are focused on too early, it is easy for someone not to learn to think for themselves and not to question assumptions, conclusions, and expert philosophies. This can do a lot of damage.

Closing Thoughts

- History matters, even though IT has always been focused on the future.
- There is more to history than “firsts” and lone geniuses.
- Successful IT innovation has always depended on maintenance, operations, logistics, and many other kinds of invisible labor.

The Work of Innovation

- ENIAC is the story of
  - Smart (to very smart)
  - Hardworking (to obsessive)
  - Flawed
- men and women who came together to do many kinds of work more or less collaboratively.
- They were in the right places at the right time, supported by bigger institutions.
- They did their jobs well enough in challenging times.
- They changed the world, without superpowers.
- All of them did that, even the secretary and the draughtswomen and the wirewomen whose faces and full names are forgotten.

Find out more…

- My website www.tomandmaria.com/tom
- Project website: www.EniacInAction.com
- Book, *ENIAC in Action: Making and Remaking the Modern Computer*, MIT Press, 2016.