ENIAC

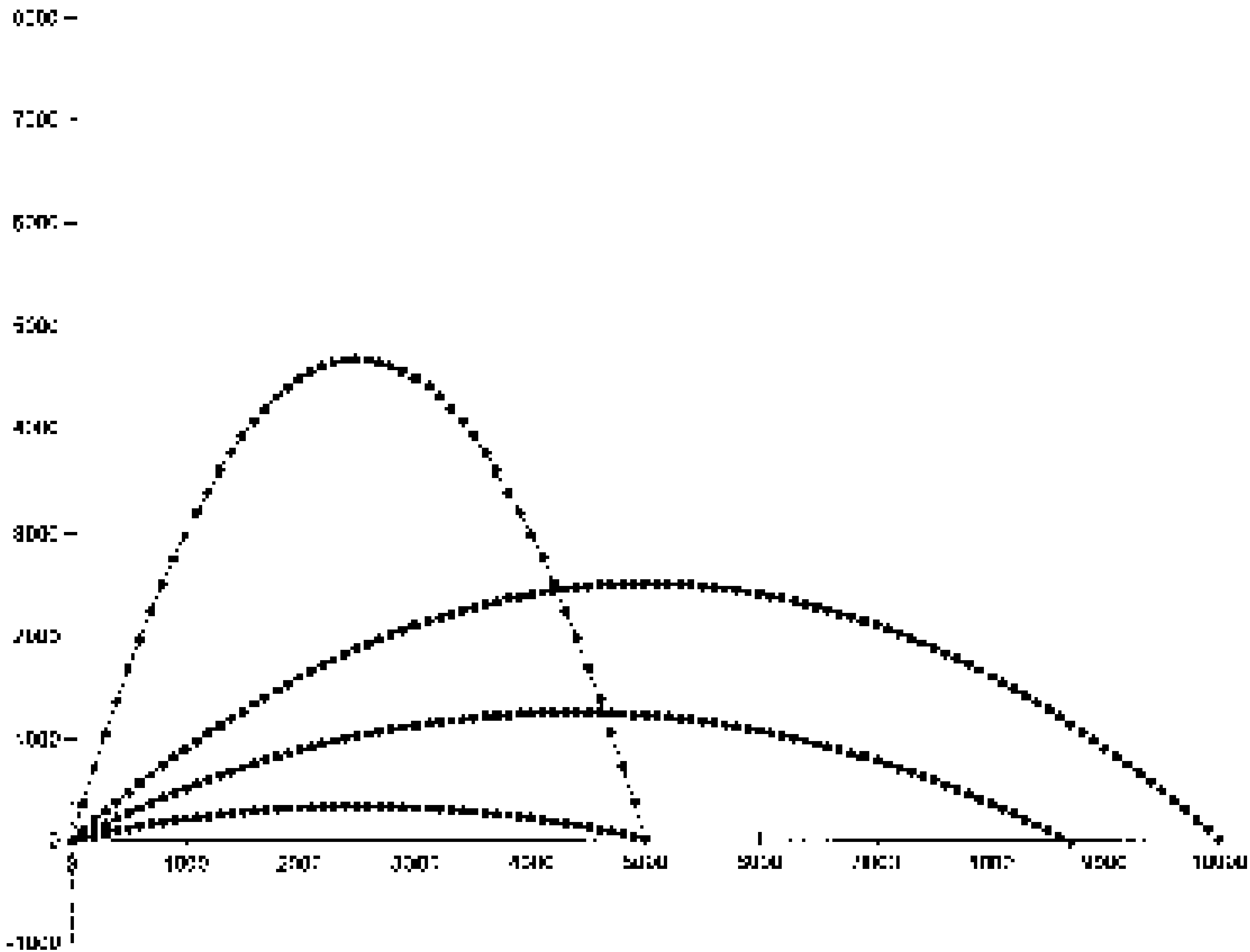
Thomas J. Bergin
Computing History Museum
American University

Electronic Numerical Integrator and Computer

- ***1st large scale electronic digital computer***
- designed and constructed at the *Moore School* of Electrical Engineering of the University of Pennsylvania
  - since 1920s, faculty had worked with Aberdeen Proving Ground's Ballistics Research Laboratory

Context

- *U.S. Army **Ballistics Research Laboratory**, Aberdeen Proving Grounds, Maryland*
- **Problems: interior and exterior ballistics**
  - interior: what happens inside a large weapon, i.e., the relationships between the charge, the projectile and the sides of the barrel
  - exterior: what happens to the projectile after it leaves the muzzle of the weapon, i.e., the effects of elevation, humidity, temperature, etc.



Harry Reid: *"You have to know where the shell will land!"*

- BRL needed to calculate a **set of firing tables** for:
- each **specific weapon**: howitzer, cannon, tank (by specific weapon system)
- for a range of **environments** (mountains, lowlands, desert, etc.), and
- for a range of **weather conditions** (temperature, humidity, rainfall, etc.)

QUADRANT ELEVATION - MILS

Height of Target - Meters

Range Meters	-400	-300	-200	-100	0	100	200	300	400	500	600	700	800	900	1000
10000	318.3	329.9	341.6	353.2	364.9	376.6	388.4	400.1	412.0	423.8	435.7	447.7	458.6	471.7	483.7
10100	323.1	334.6	346.1	357.7	369.4	381.0	392.7	404.6	416.2	428.0	439.9	451.8	463.7	475.7	487.7
10200	327.8	338.3	350.8	362.3	373.9	385.6	397.1	408.8	420.5	432.3	444.1	455.8	467.8	479.7	491.7
10300	332.6	344.0	355.5	366.9	378.4	390.0	401.6	413.2	424.9	436.6	448.4	460.2	472.0	483.9	495.8
10400	337.6	348.8	360.2	371.6	383.1	394.6	406.1	417.7	429.3	441.0	452.7	464.4	476.2	488.1	500.0
10500	342.3	353.6	364.9	376.3	387.7	399.2	410.6	422.2	433.8	445.4	457.1	468.8	480.5	492.4	504.2
10600	347.2	358.4	369.7	381.0	392.4	403.8	415.2	426.7	438.3	449.9	461.5	473.2	484.9	496.7	508.6
10700	352.1	363.3	374.5	385.8	397.1	408.5	419.9	431.4	442.9	454.4	466.0	477.7	489.4	501.2	513.0
10800	357.1	368.2	379.4	390.6	401.9	413.2	424.6	436.0	447.6	459.0	470.6	482.2	493.9	505.7	517.6
10900	362.1	373.2	384.3	395.5	406.7	418.0	429.4	440.8	452.2	463.7	475.3	486.9	498.6	510.3	522.1
11000	367.1	378.1	389.2	400.4	411.6	422.9	434.2	445.6	457.0	468.4	480.0	491.6	503.2	515.0	526.8
11100	372.2	383.2	394.2	405.4	416.5	427.8	439.0	450.4	461.8	473.3	484.8	496.4	508.0	519.8	531.6
11200	377.3	388.2	399.3	410.4	421.6	432.7	444.0	455.3	466.7	478.1	489.7	501.2	512.9	524.6	536.5

The burden of calculations....

- In 1920s and 1930s, BRL scientists used manual calculators and slide rules to perform ballistics calculations;
  - 60 second trajectory took **20 hours** using a desk calculator! Firing table contained hundreds of these
- In 1937, BRL started using IBM Punched Card machinery to calculate ballistics trajectories and to perform other ballistics calculations.

Enter technology....

- **1935** With assistance from Moore School, a Differential Analyzer is operational (analog)
  - ***calculate a trajectory in 15 minutes***
- **June 1944** Bell Model III, **Ballistic Computer** operational at BRL
- **1944 IBM Pluggable Sequence Relay Calculator**
  - *Aberdeen Proving Ground, Aberdeen, MD*
  - *Naval Proving Ground, Dahlgren, VA*

John Mauchly (1907-1980)

- Physics instructor, Ursinus College, attends a wartime course on electronics at Moore School
- Attends AAS meeting **December 1940**

and meets John V. Atanasoff of Iowa State Univ.

- Working on problems of *weather prediction*
- Visits Atanasoff in Iowa, June 1941
- writes **"The Use of High Speed Vacuum Tube Devices for Calculating" August 1942**

at the U. Of Pennsylvania (*ignored!*)

The Use of High Speed Vacuum Tube Devices for Calculating by John Mauchly, 1942

There are many sorts of mathematical problems which require calculation by formulas which can...be put in the form of **iterative equations**. Purely mechanical calculating devices can be devised to expedite the work. However, a great gain in the speed of the calculation can be obtained if the devices which are used **employ electronic means for the performance of the calculation**, because the speed of such deices can be made very much higher than that of any mechanical device. It is the purpose of this discussion to consider the...advantages...of **electronic circuits which are interconnected**...to perform...multiplication's , additions, subtractions or divisions in sequence, and which can therefore be used for the **solution of difference equations**.

- As will be brought out in the following discussion, the **electronic *computor*** may have certain advantages other than...speed when compared to the ***differential analyser***...whereas the electronic device, operating solely on the principal of counting, can, without great difficulty, be made as accurate as required for any practical purpose. Secondly...errors...are mathematically determined errors.... Thirdly, the ease with which the various components of such a computing device can be interconnected by cables and switching units makes it possible to set up a new problem without much difficulty.
- As already stated, the **electronic computor** utilizes the ***principal of counting*** to achieve its results....

J. Presper Eckert (1919-1995)

- Met John Mauchly while a graduate student supervising laboratory work for a war-time electronics class **1941**
- did wartime research on radar and delay line memories for radar devices
- Chief Engineer on ENIAC
- Contract signed when he was 24 years old
- **First electronic digital engineer**

Herman Heine Goldstine (1913-)

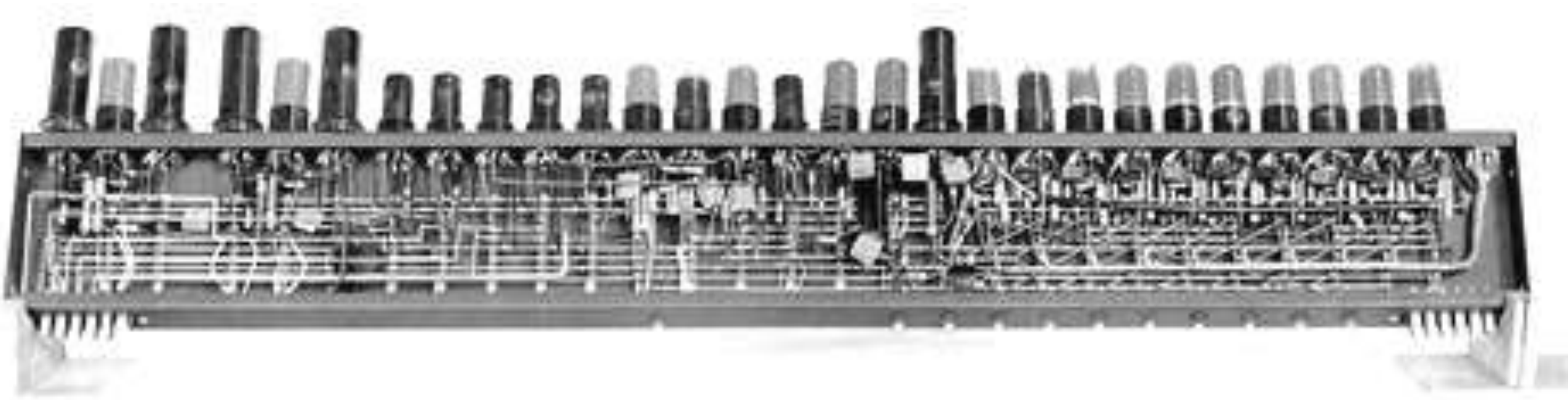
- University of Chicago Ph.D. Assistant Professor of Mathematics before war
- Assigned to BRL, as a 2nd Lieutenant because he had a course in ballistics!
- Oversees U Penn efforts to calculate firing tables using manual methods (a need)
- Heard about Mauchly's interest in computation
- Arranged a meeting for **April 9, 1943** to discuss a possible contract with the Army

Inspiration and Perspiration Unite

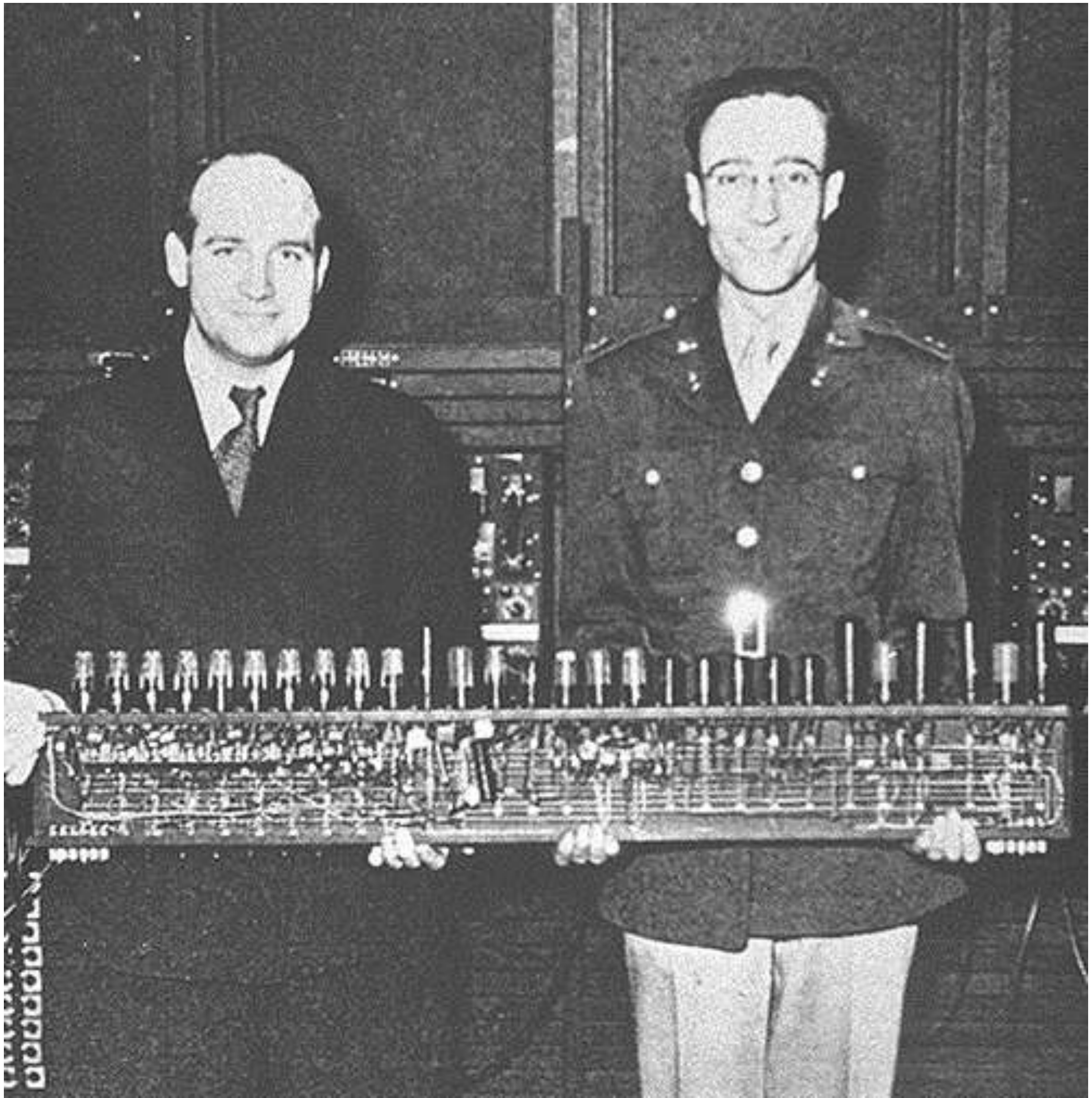
- **1943** Mauchly and Eckert prepare a proposal for the US Army to build an Electronic Numerical Integrator
  - **calculate a trajectory in 1 second**
- **May 31, 1943** Construction of ENIAC starts
- **1944** early thoughts on **stored program** computers by members of the ENIAC team
- **July 1944** two ***accumulators*** working

Accumulator

(28 vacuum tubes)



Pres Eckert and Herman Goldstine



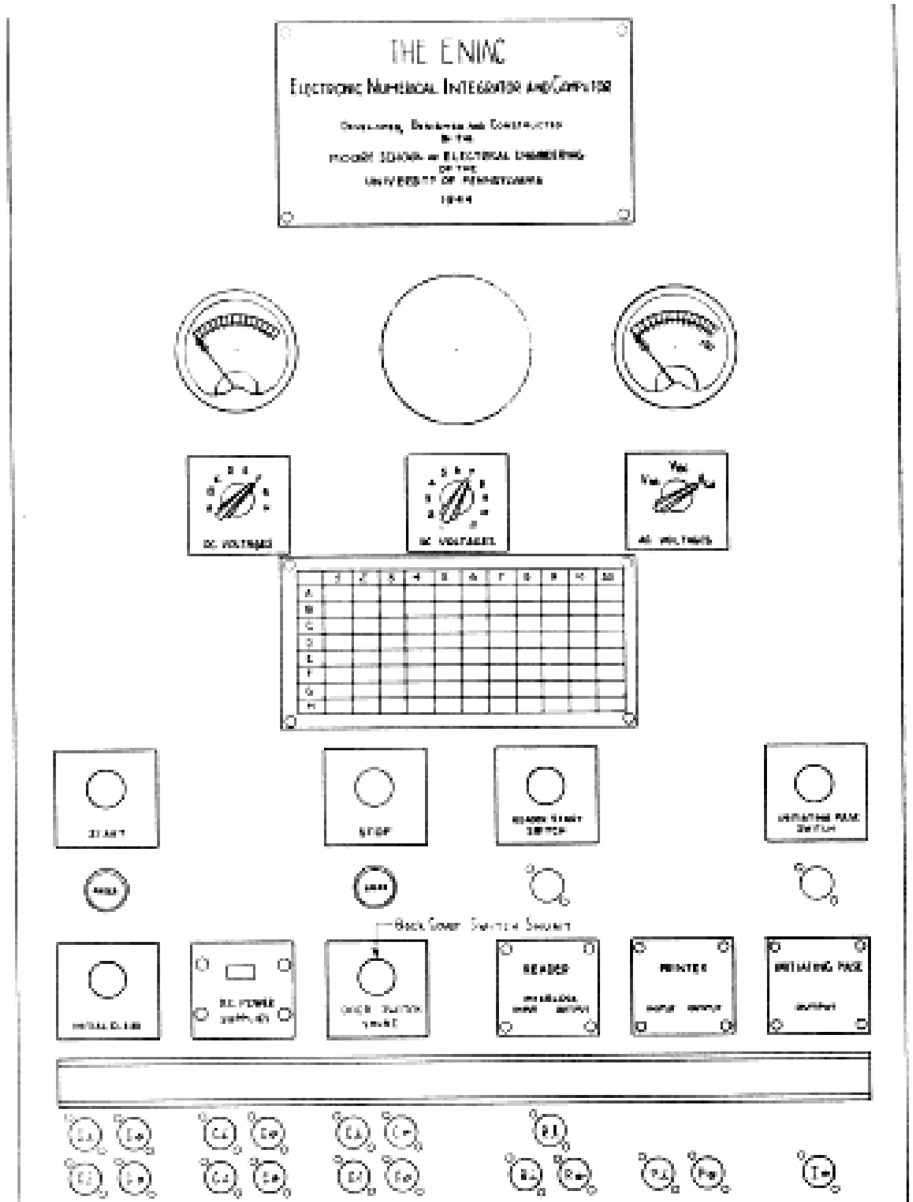
Engineers and *orders of magnitude*

- Engineers build structures such as bridges and tall buildings; size improves cautiously!
  - Build a 4 story building; next do a 6 story one
- Largest electronic device (a classified radar) contained 300 to 400 vacuum tubes.
- ENIAC was to contain **18,000 vacuum tubes**
- **Project criticized** by just about all: size, reliability, etc. [*fear of the unknown]*

Contract

- ***"...for research and experimental work in connection with the development of an electronic numerical integrator and computer...."***
- ***electronic*** Mauchly's idea of vacuum tubes
- ***numerical*** calculate by addition only
- ***integrator*** from the Differential Analyzer
- ***and computer*** per Col. Paul Gillon

General Barnes & Col. Paul Gillon



Ci - pulse input terminal for selective clearing

Co - pulse output terminal for selective clearing

Ri - pulse input terminal for reader interlock signal

Ri - pulse input terminal for reader

Ro - pulse output terminal for reader

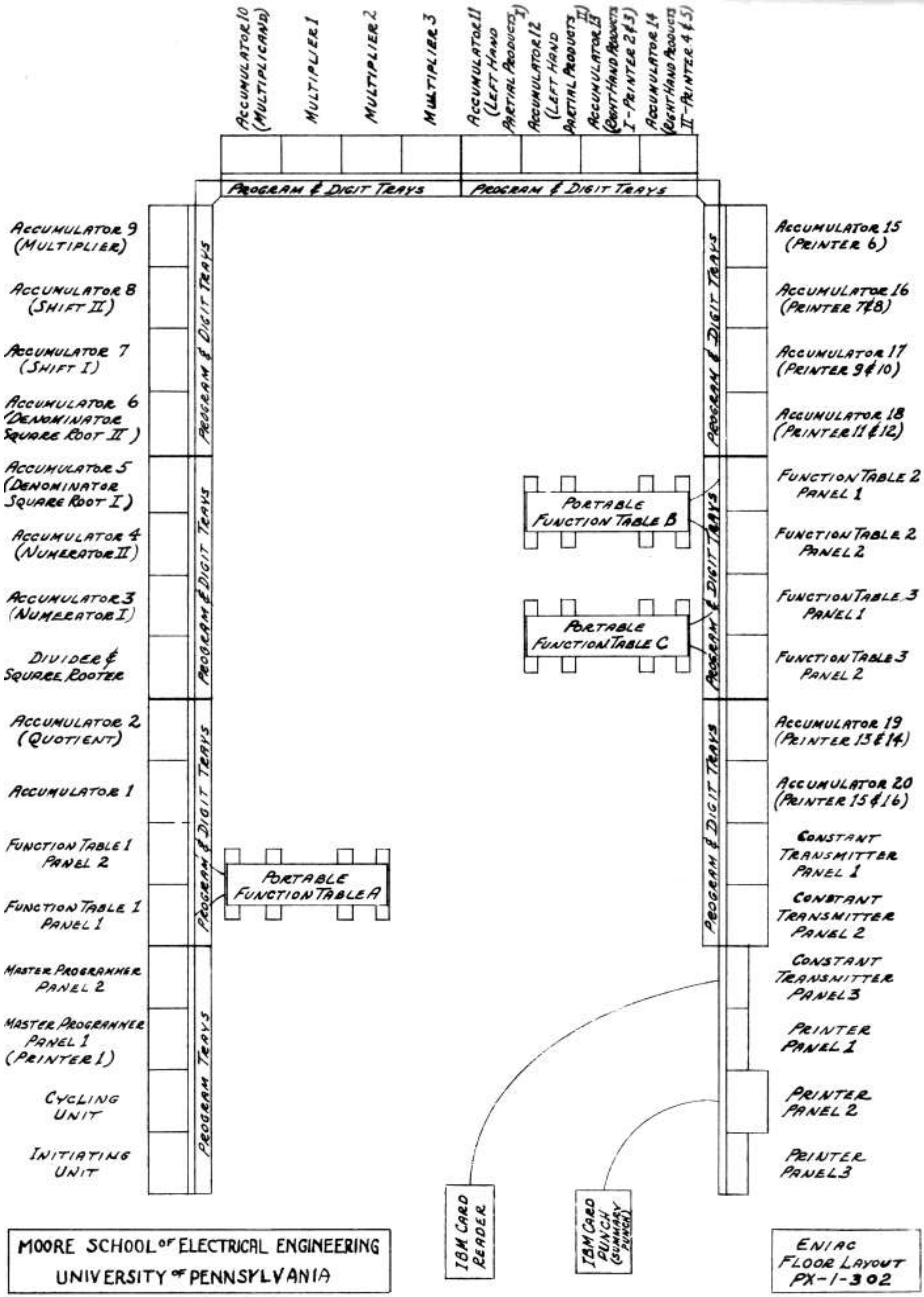
INITIATING DEVICE
FRONT PANEL
PX-9-302 R

Pres Eckert

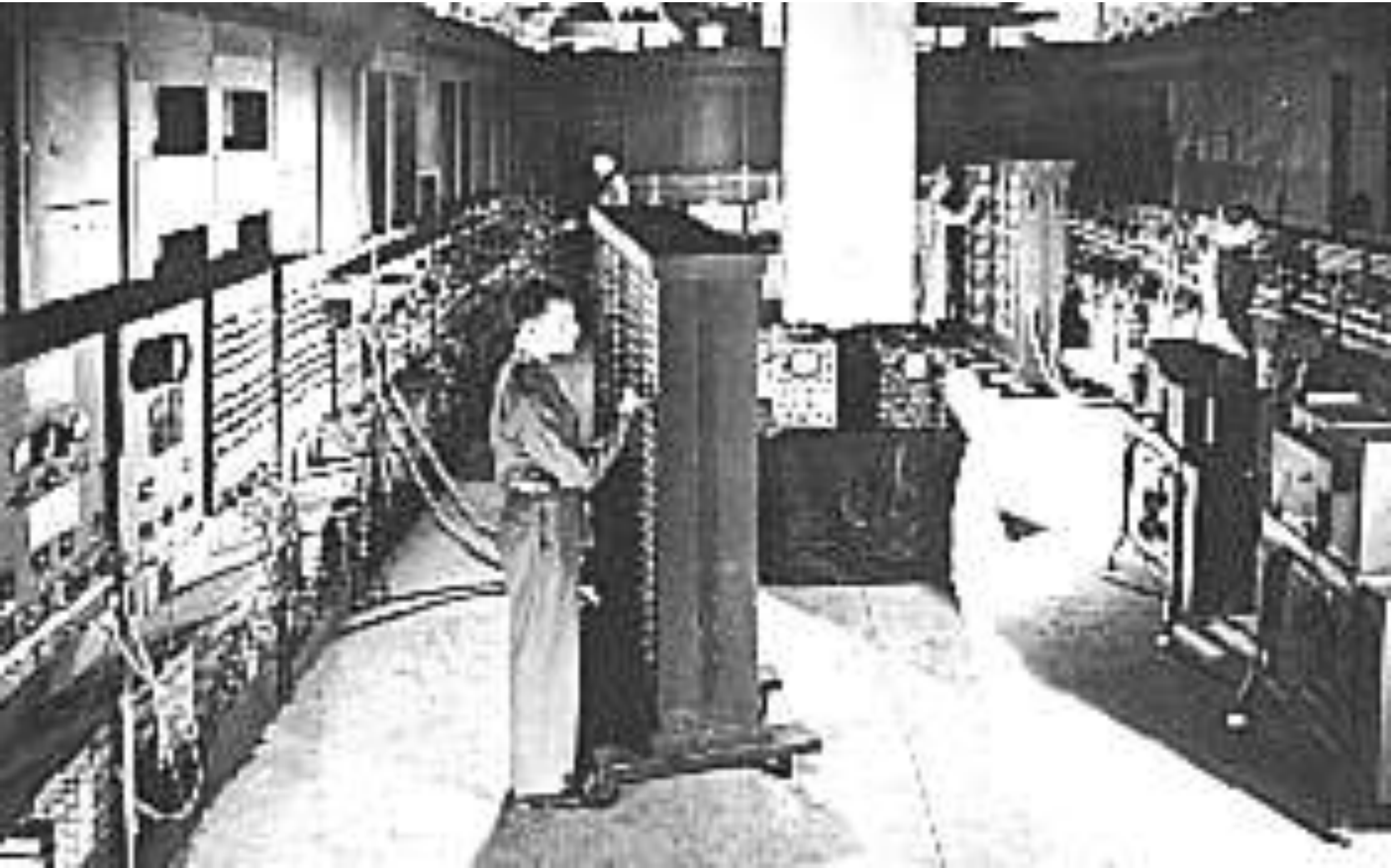
- ***Conservative*** design:
  - Pres Eckert: "...we called ***worst-worst design***..." (to design components so that they could operate out of tolerance or specification)
- prior ***testing*** and ***burning in*** of tubes
- ***modular construction*** for ease of maintenance
  - individual units which slid in and out

Architecture

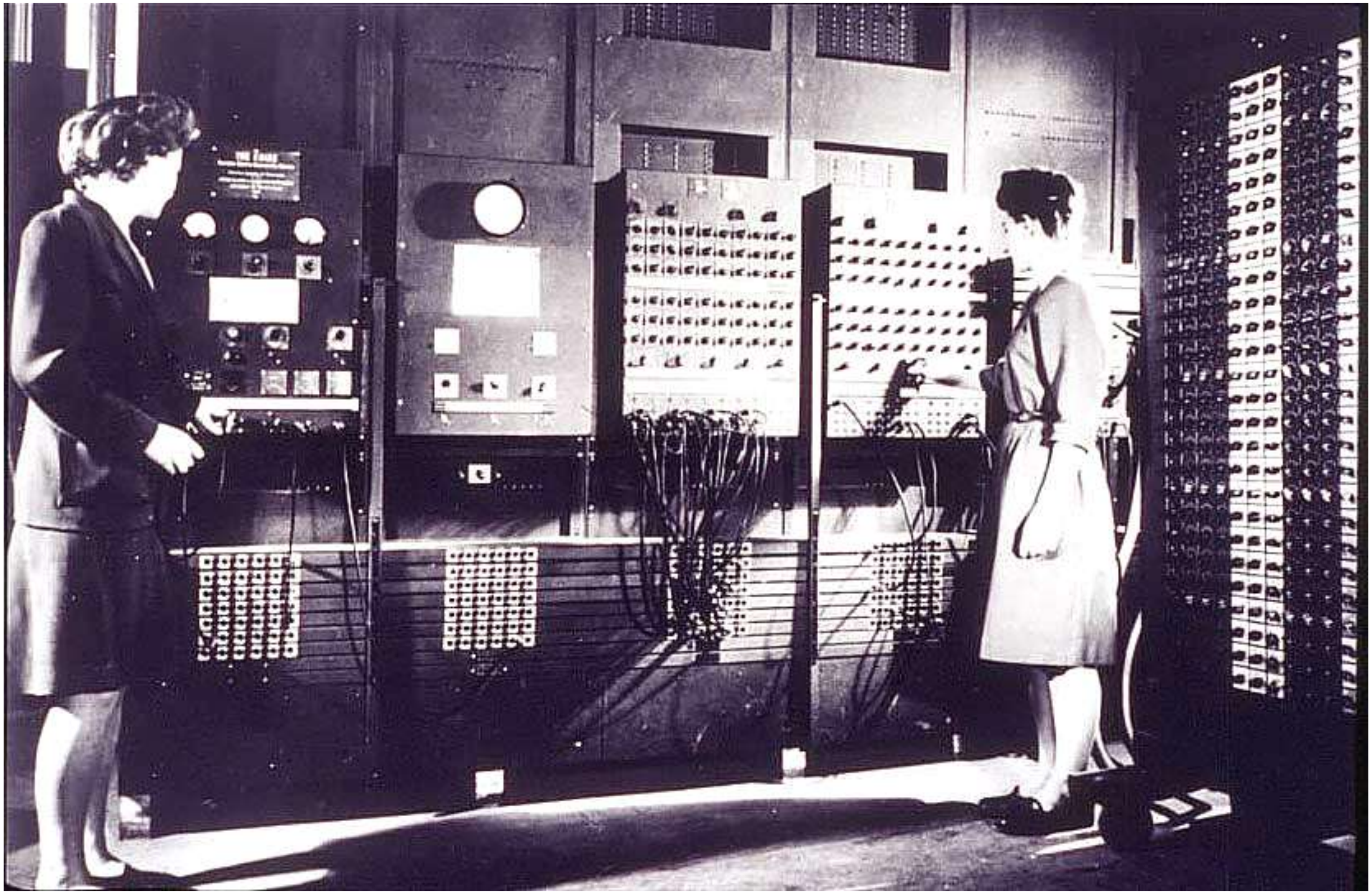
- **20 Accumulators** (decimal 10-digit signed numbers) which acted like registers
  - what went in was added to total
  - "clear the accumulator"
- **Multiplication Unit**
- **Division and Square Root Unit**
- **Master Programmer** ***for sequencing***
- **Input and Output Units:** ***punched cards***
- **3 Function Tables** for storing constant values
  - used decade switches; idea used in Harvard Mark I


ACCUMULATOR 10 (MULTIPLICAND)
MULTIPLIER 1
MULTIPLIER 2
MULTIPLIER 3
ACCUMULATOR 11 (LEFT HAND PARTIAL PRODUCTS I)
ACCUMULATOR 12 (LEFT HAND PARTIAL PRODUCTS II)
ACCUMULATOR 13 (RIGHT HAND PRODUCTS I - PRINTER 2 & 3)
ACCUMULATOR 14 (RIGHT HAND PRODUCTS II - PRINTER 4 & 5)
PROGRAM & DIGIT TRAYS
PROGRAM & DIGIT TRAYS
ACCUMULATOR 9 (MULTIPLIER)
ACCUMULATOR 8 (SHIFT II)
ACCUMULATOR 7 (SHIFT I)
ACCUMULATOR 6 (DENOMINATOR SQUARE ROOT II)
ACCUMULATOR 5 (DENOMINATOR SQUARE ROOT I)
ACCUMULATOR 4 (NUMERATOR II)
ACCUMULATOR 3 (NUMERATOR I)
DIVIDER & SQUARE ROOTER
ACCUMULATOR 2 (QUOTIENT)
ACCUMULATOR 1
FUNCTION TABLE 1 PANEL 2
FUNCTION TABLE 1 PANEL 1
MASTER PROGRAMMER PANEL 2
MASTER PROGRAMMER PANEL 1 (PRINTER 1)
CYCLING UNIT
INITIATING UNIT
PROGRAM & DIGIT TRAYS
PROGRAM & DIGIT TRAYS
PROGRAM & DIGIT TRAYS
PROGRAM TRAYS
PORTABLE FUNCTION TABLE A
PORTABLE FUNCTION TABLE B
PORTABLE FUNCTION TABLE C
ACCUMULATOR 15 (PRINTER 6)
ACCUMULATOR 16 (PRINTER 7 & 8)
ACCUMULATOR 17 (PRINTER 9 & 10)
ACCUMULATOR 18 (PRINTER 11 & 12)
FUNCTION TABLE 2 PANEL 1
FUNCTION TABLE 2 PANEL 2
FUNCTION TABLE 3 PANEL 1
FUNCTION TABLE 3 PANEL 2
ACCUMULATOR 19 (PRINTER 13 & 14)
ACCUMULATOR 20 (PRINTER 15 & 16)
CONSTANT TRANSMITTER PANEL 1
CONSTANT TRANSMITTER PANEL 2
CONSTANT TRANSMITTER PANEL 3
PRINTER PANEL 1
PRINTER PANEL 2
PRINTER PANEL 3
PROGRAM & DIGIT TRAYS
PROGRAM & DIGIT TRAYS
PROGRAM & DIGIT TRAYS
IBM CARD READER
IBM CARD PUNCH (SUMMARY PUNCH)
MOORE SCHOOL OF ELECTRICAL ENGINEERING
UNIVERSITY OF PENNSYLVANIA
ENIAC
FLOOR LAYOUT
PX-1-302

ENIAC at Moore School, U.Penn

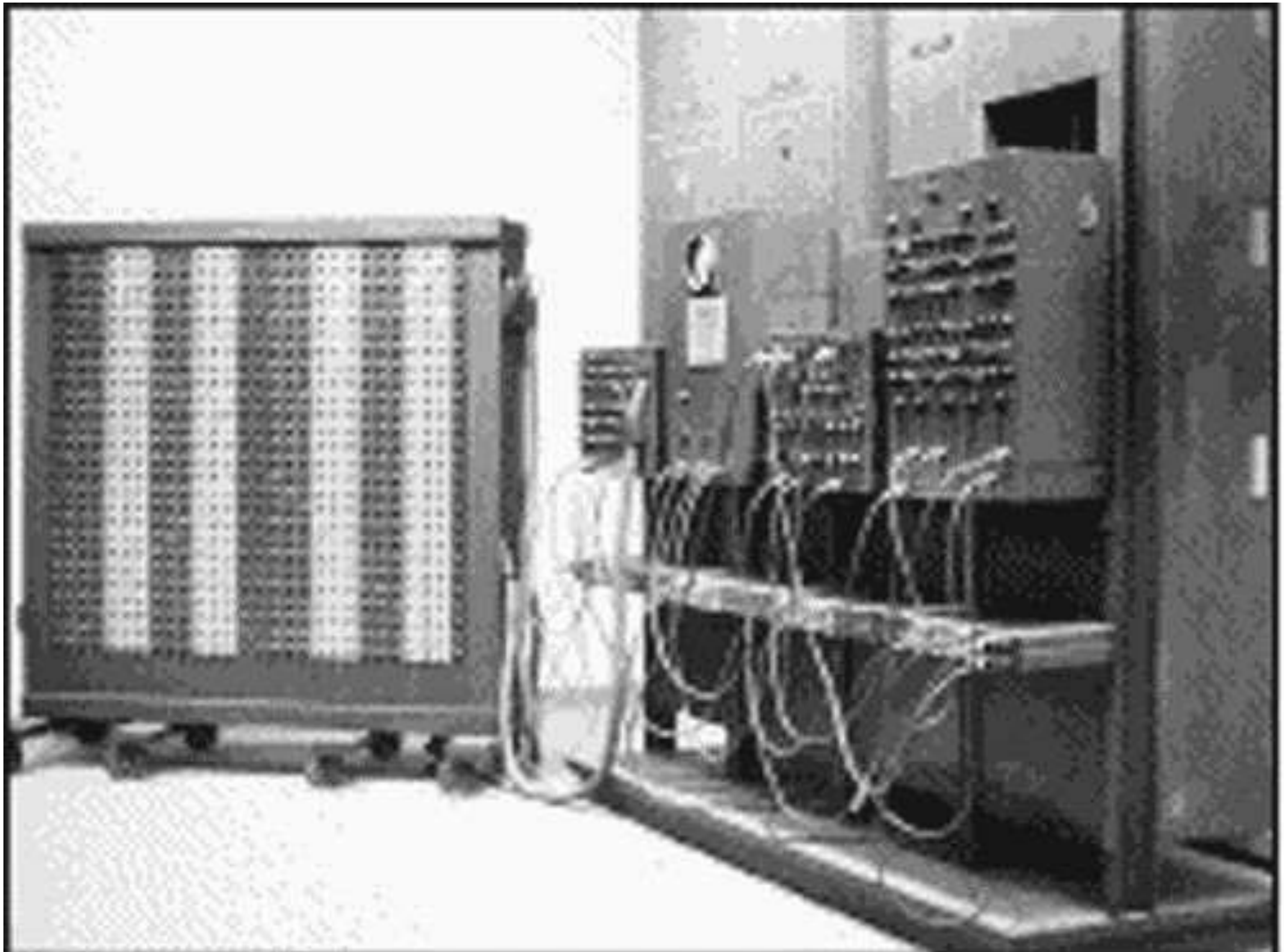


Betty Jennings and Frances Billas

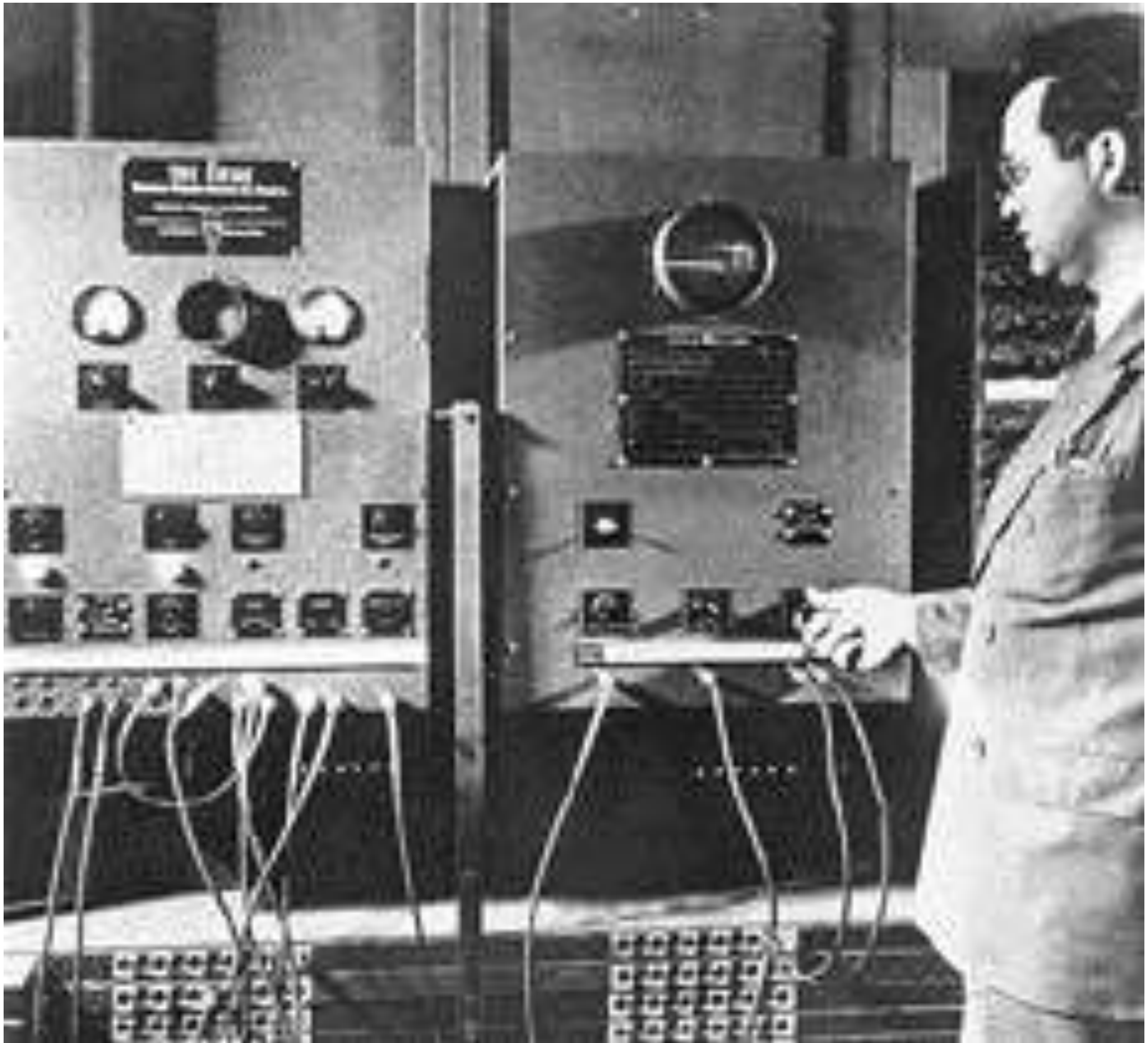


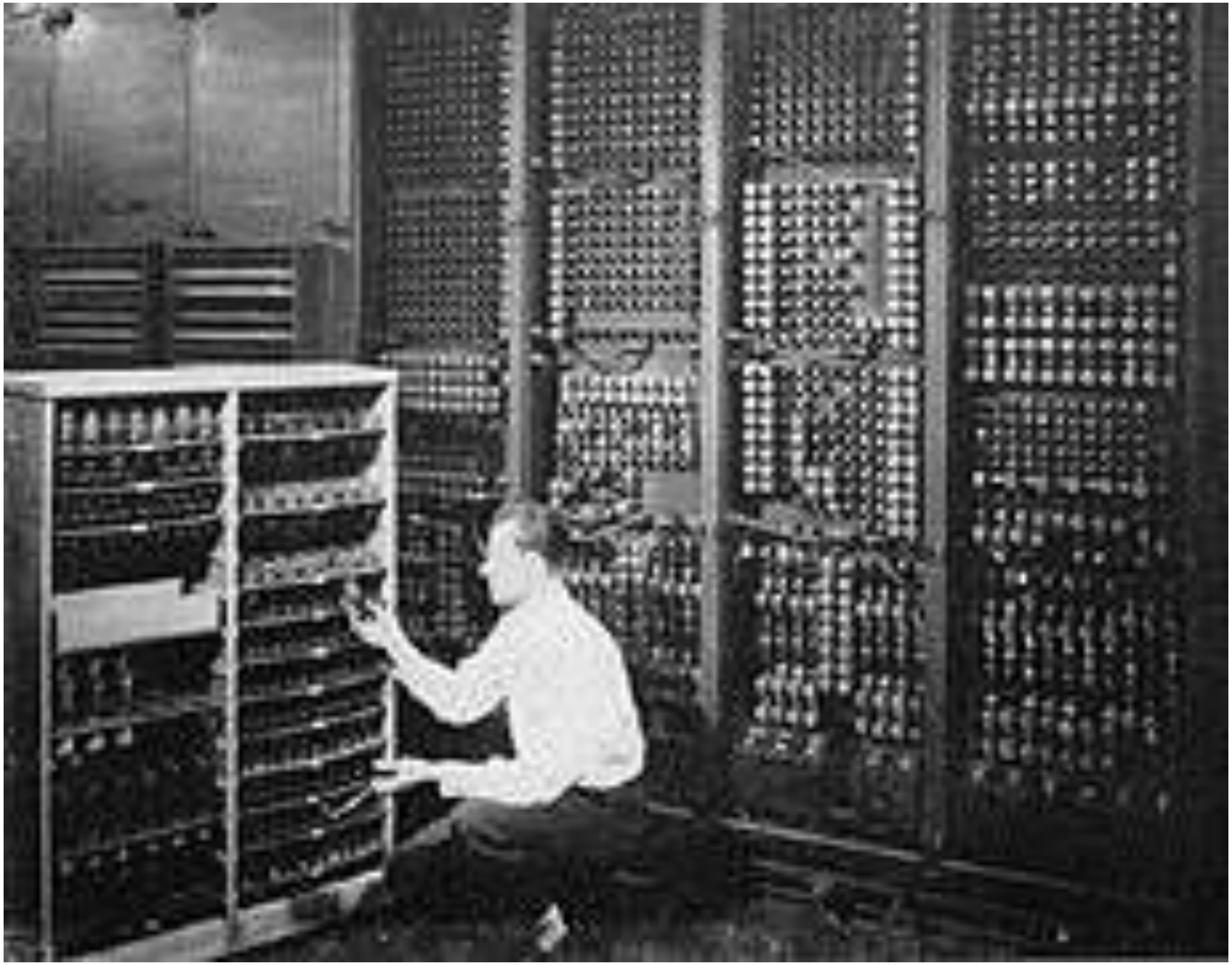
John Mauchly and Pres Eckert

Function Table



Harry Huskey



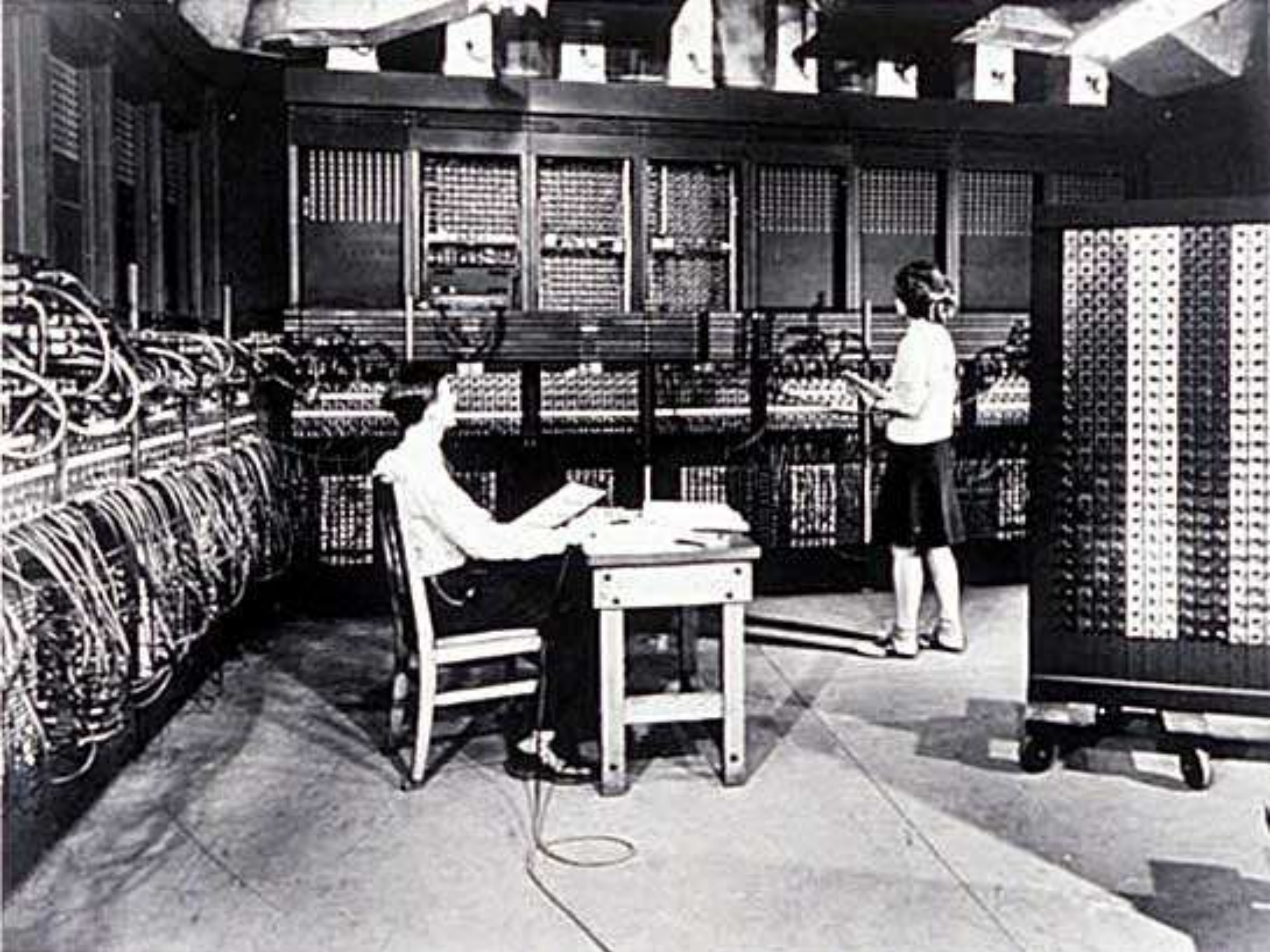


Cables, cables, and more cables!

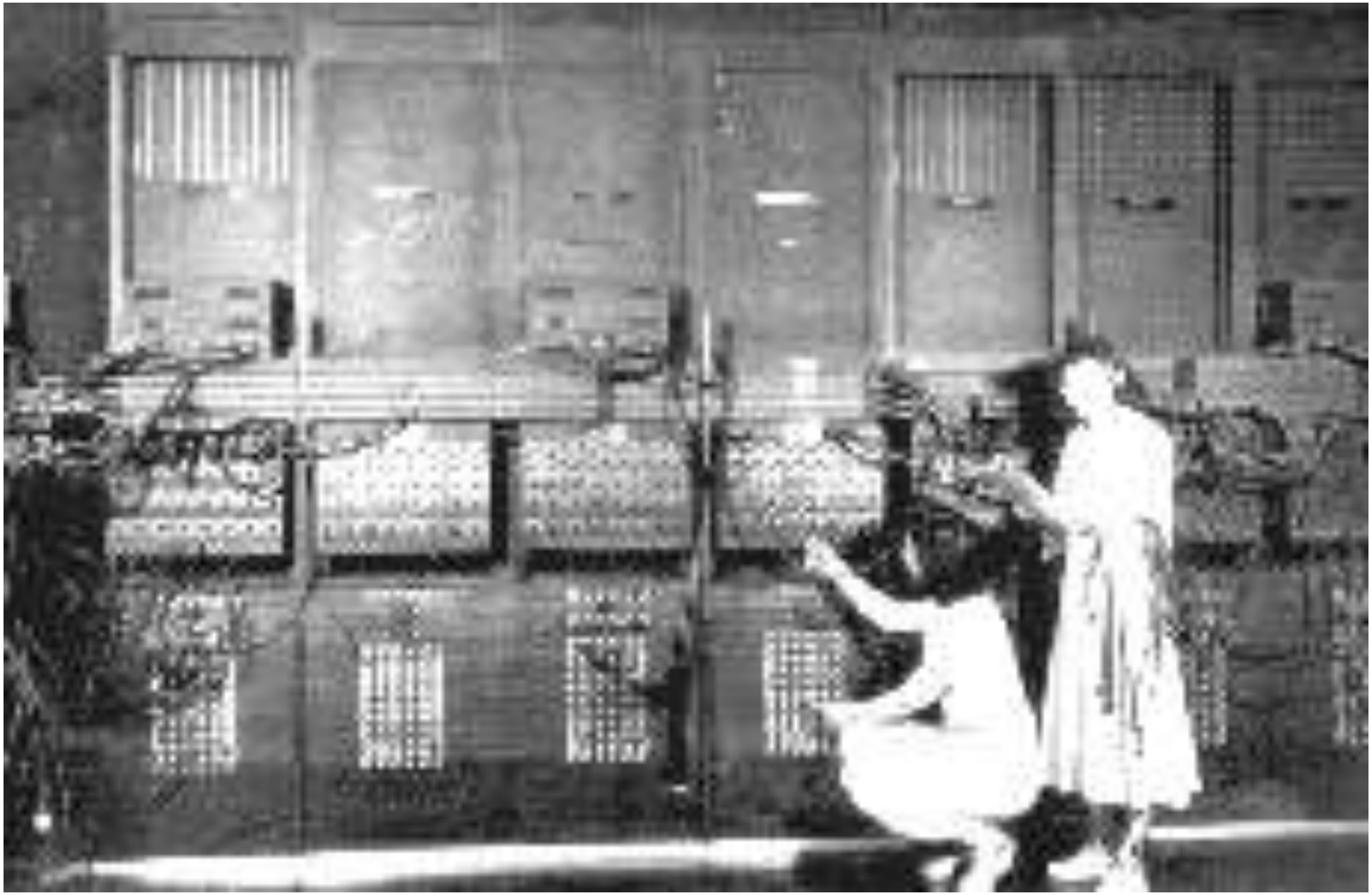
- **U shape; 40 units; 130 feet long**
  - 40 units; 3 function tables; 2 Input/output units
  - constructed in Moore School basement
- Electronic pulses moved from unit to unit through **cables** which lay in **digit trays:**
  - **data bus**
  - **control bus**
- Cooled by forced air (air conditioning!)
  - people wanted to work in the machine room

"Setting up the problem"

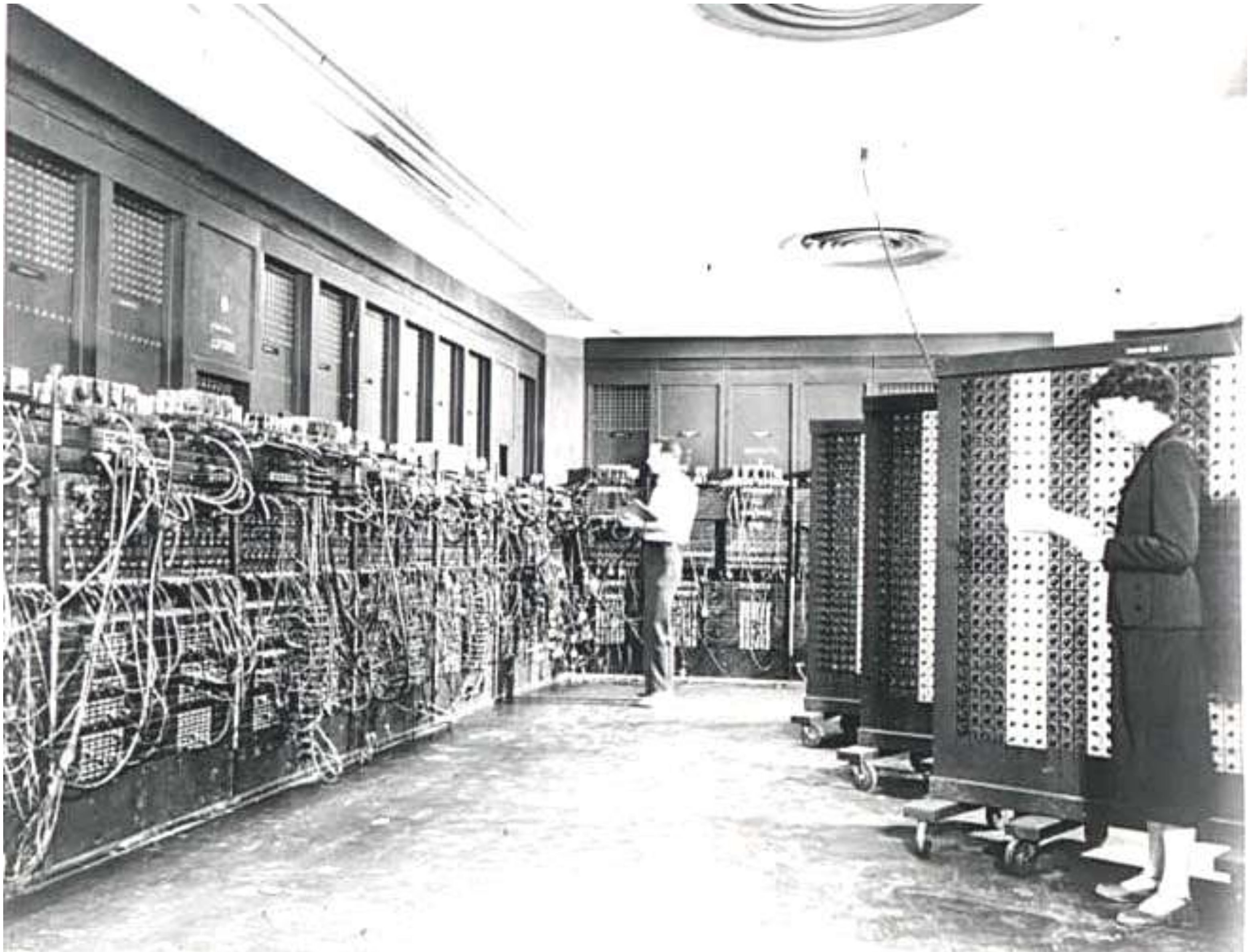
- **ENIAC was NOT a "stored program" device**
- For each problem, someone analyzed the arithmetic processing needed and prepared wiring diagrams for the ***computors*** to use when wiring the machine
- Process was **time consuming** and error prone
- Cleaning personnel often knocked cables out of their place and just put them back *somewhere*

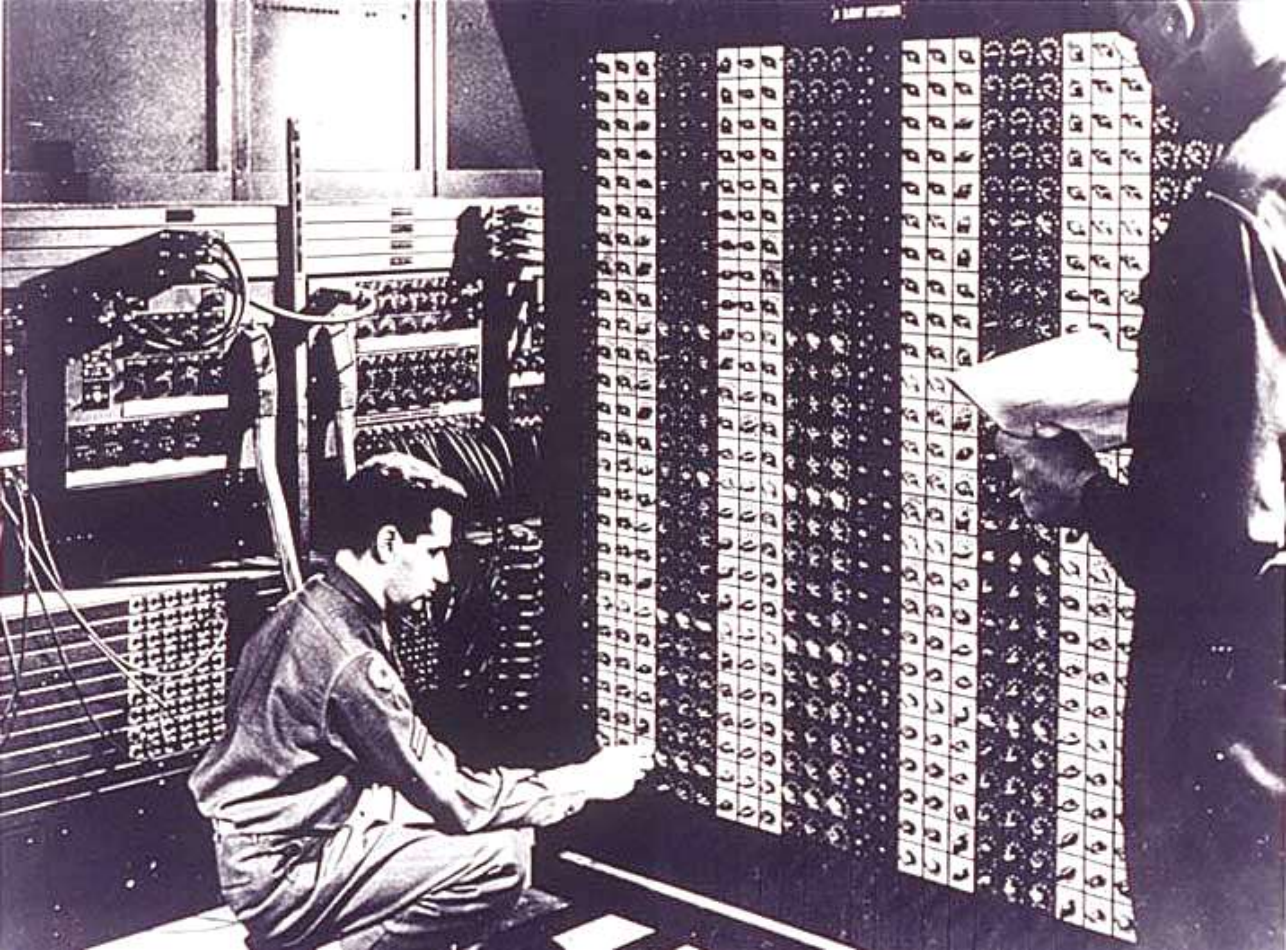


Wiring the machine

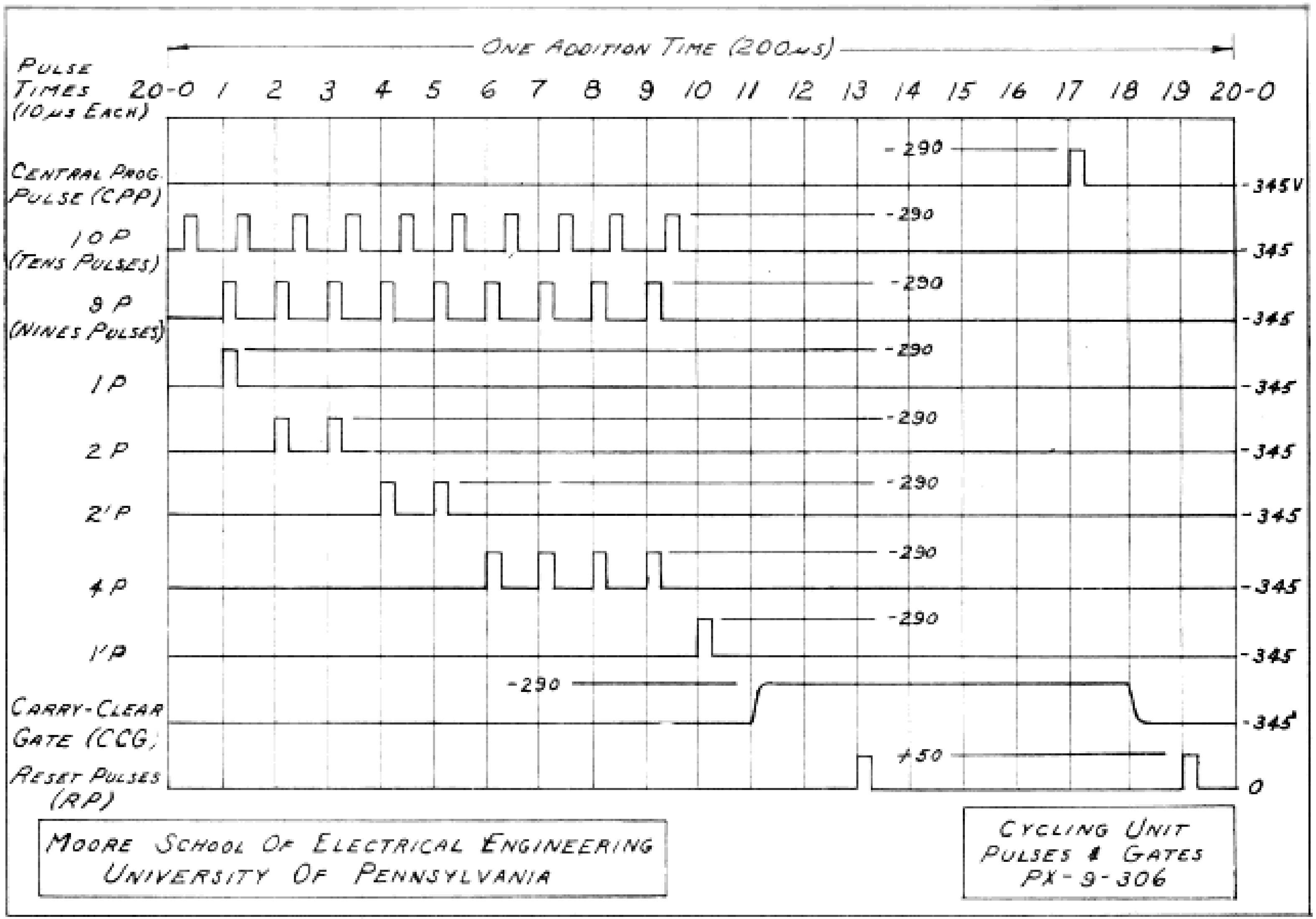


Function Tables





Pulse Diagram



Specifications (**Weik, *BRL Rpt 971***)

- **Number of Circuit Elements:**
  - Tubes: 17,468
  - Tube types: 16
  - Crystal diodes: 7,200
- **Arithmetic Unit:**
  - add time: 200 microseconds
  - multiply time: 2,800 microseconds
  - divide time: 24,000 microseconds
  - basic pulse repetition rate: 60-125 kilocycles/sec
  - arithmetic mode: **parallel** (as a serial train of pulses)

- **Physical Factors:**
  – Power consumption: 174 kW
  – Space occupied: 7,200 (square feet)
- **Personnel Requirements:**
  – Daily operation: 3 8-hour shifts, 6 Technicians, 7 days/week
- **Reliability and Operating Experience**
  – Unit passed acceptance test: 1946
  – Average error free running time: 5.6 hours
- **Additional Features and Remarks:**
  – There are four modes of operation: continuous, pulse time, add time, or instruction time

Milestones and Millstones....

- **September 1944** John von Neumann visits project
  – Goldstine's meeting at Aberdeen Train Station
- **October 1944** Army extends the ENIAC contract to cover research on the EDVAC stored-program concept
- **Spring 1945** ENIAC working well
- **June 1945** ***First Draft of a Report on the EDVAC***
- **1946** Eckert and Mauchly leave the Moore School and establish the **Electronic Control Company**

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

DrLeutert/ehm/21208

TO : Director, BRL DATE: 8 September 1954

FROM : Chief, Computing Laboratory, BRL

SUBJECT: Use of Computing Machines

1. The BRL computing machines performed well above average during the month of August. The following figures compare this performance with the one obtained during the first six months of 1954:

Average weekly figures in hours for period 30 July - 27 August 1954:

	ORDVAC	EDVAC	ENIAC
Available	143.4	129.9	124.0
Idle	16.2	40.4	0.1
Use	127.2	89.5	123.9
Available / 168	85%	77%	74%

Average weekly figures in hours for first six months of 1954:

	ORDVAC	EDVAC	ENIAC
Available	109.5	103.5	82.0
Idle	8.2	45.6	15.5
Use	101.3	57.9	66.5
Available / 168	65%	62%	49%

Average weekly number of problem changes:

	ORDVAC	EDVAC	ENIAC
First six months 1954	210.3	56.8	9.4
August 1954	280.2	175.5	25.8

Average weekly number of problems:

	ORDVAC	EDVAC	ENIAC
First six months 1954	33.5	18.0	5.0
August 1954	37.0	26.8	6.8

2. The figures show clearly that we have just about reached full use of our computing machine capacity. Although summer employees have contributed considerably to the increase in machine time used for computations, I estimate that by the end of 1954 we will either reach the limit of our capacity or our machines will have to perform much better than they have in the past. In order to avoid delays we intend to concentrate on reducing the machine time required for finding errors in a new code.

W. W. Leutert

W. W. LEUTERT

Commitment file

Pres Eckert, John Brainerd,Samuel Feltman, Capt Herman Goldstine, John Mauchly, Dean Pender, Gen Barnes, Col Paul Gillon

Report on

THE ENIAC

(Electronic Numerical Integrator and Computer)

Developed under the supervision of the
Ordnance Department, United States Army

TECHNICAL REPORT I
Volume I
(Bound in two volumes)

UNIVERSITY OF PENNSYLVANIA
Moore School of Electrical Engineering
PHILADELPHIA, PENNSYLVANIA

June 1, 1946

- **March 1947 EDVAC** *delay line memory* working
- **1947 ENIAC converted to an elementary stored-program computer via the use of function tables**
  - *BRL Report No. 673, A Logical Coding System Applied to the ENIAC*, R.F. Clippinger, 29 September 1948
- **1951 Core memory module added to the ENIAC**
  - BRL Memorandum Report No. 582, *Description of the Eniac (sic) Converter Code*, W. Barkley Fritz, December 1961
- **October 1955 ENIAC shut off**
  - *Mina Rees rescues units from a field*

President Truman visits APG

References

- Nancy Stern, ***From ENIAC to UNIVAC, An Appraisal of the Eckert-Mauchly Computers***, Digital Press, 1981 [major research effort]
- **Herman H. Goldstine**, *The Computer, from Pascal to von Neumann*, Princeton University Press, 1972
  - Goldstine was a ***participant***
- N. Metropolis, et.al., *A History of Computing in the Twentieth Century*, **Academic Press, 1980**
- **Brian Randell, ed.,** *The Origins of Digital Computers*, Springer-Verlag, 1973

Additional References

- **Arthur W. Burks** and Alice R. Burks, "The ENIAC: First General-Purpose Electronic Computer," *Annals*, Vol.3, No.4 ***[participant***]
- **Barkley Fritz**, "ENIAC--A Problem Solver," *Annals*, Vol.16, No. 1 (1994) ***[worked on ENIAC]***
- Barkley Fritz, "The Women of ENIAC," *Annals*, Vol.18, No.3 (Fall 1996)
- **Herman H. Goldstine**, "Computers at the University of Pennsylvania's Moore School, 1943-1946, *Proceedings of the American Philosophical Society*, Vol 136, No1 (1992) ***[participant***]

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- **H.H. Goldstine**, "The Electronic Numerical Integrator and Computer (ENIAC)," pp. 10-16.
- Dilys Winegrad, "The Birth of Modern Computing: The Fiftieth Anniversary of a Discovery At The Moore School of Engineering of the University of Pennsylvania," pp..5-9.
- Mitchell Marcus and Atsushi Akera, "Exploring The Architecture of an Early Machine: The Historical Significance of the ENIAC Machine Architecture, pp.. 17-24

IEEE Annals, 18/1, Spring 1996

- Peter Eckstein, “J. Presper Eckert,” pp..25-44
- John Costello, “As the Twig is Bent: The Early Life of John Mauchly,” pp.45-50
- David Alan Grier, “The ENIAC, the Verb “to program” and the Emergence of Digital Computers,” pp.51-55

Show and Tell

- **Firing Table from APG**
- ***Moore School Lectures***
- ***ENIAC Manuals (Adele Goldstine)***
- **Original drawings**
- Photographs (include 50th Anniversary)
- **diagrams!!!!!!!!**
- 25th anniversary brochures, medal, etc.