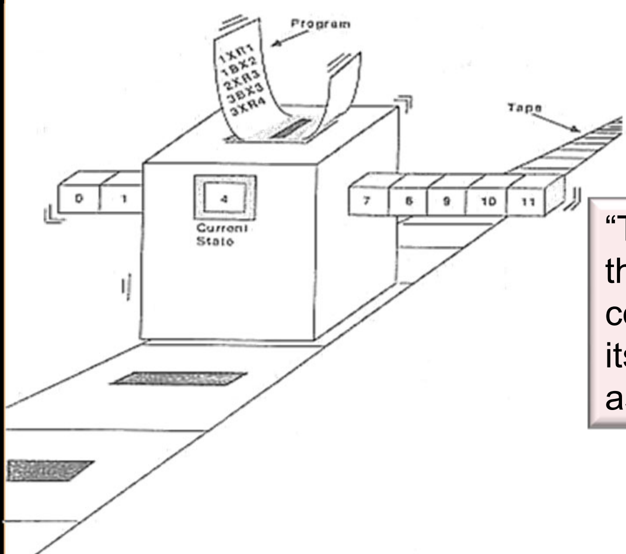
lecture 4

# General-purpose computers

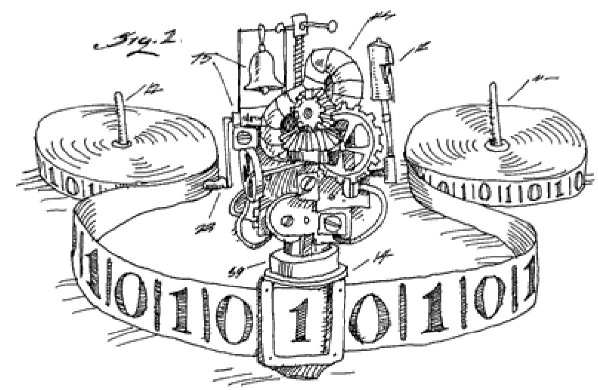
## A fundamental principle of computation

- "On computable numbers with an application to the *Entscheidungsproblem*"
  - Turing, A. M. *Proc. Lond. Math. Soc.* **s2–42**, 230–265 (1936–37).
    - **Turing machine**, universal computation, decision problem
  - **Machine**'s *state* is *controlled* by a *program*, while *data* for program is on limitless **external tape**
    - every machine can be described as a **number** that can be stored on the tape (for itself or another machine)
      - Including a Universal machine
    - **distinction** between *numbers that mean things* (data) and *numbers that do things* (program)




code

"The fundamental, indivisible unit of information is the bit. The fundamental, indivisible unit of digital computation is the transformation of a bit between its two possible forms of existence: as [memory] or as [code]. George Dyson, 2012.



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A fundamental principle of computation

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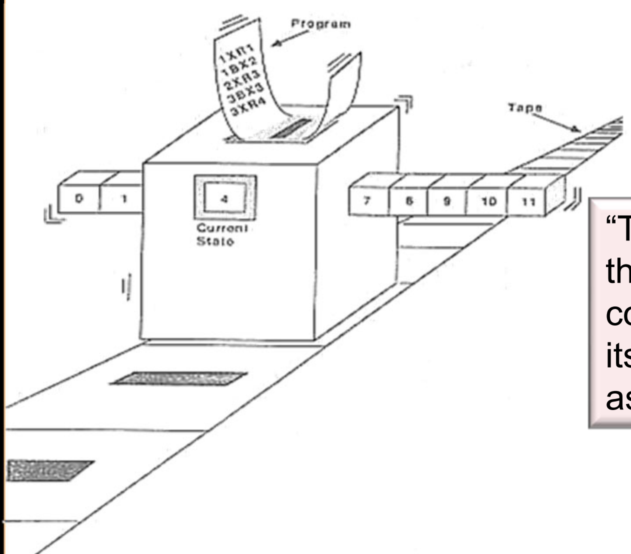


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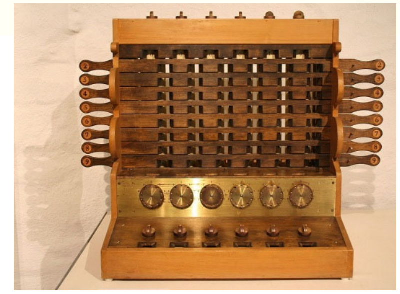
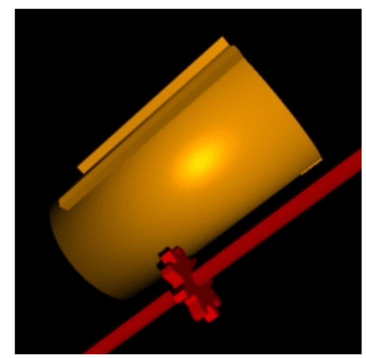
## analog machines

- Wilhelm Schickard (1592- 1635)
  - In 1623 built the first mechanical calculator
    - can work with six digits, and carries digits across columns. It works, but never makes it beyond the prototype stage.
- Blaise Pascal (1623-1662)
  - built a mechanical calculator in 1642
    - It has the capacity for eight digits, but has trouble carrying and its gears tend to jam.
    - 10-teeth gears
- Gottfried von Leibniz (1614-1716)
  - built a mechanical calculator in 1670 capable of multiplication and division
    - (shift) registers for binary arithmetic
    - Credited Chinese for Binary arithmetic (I-Ching)
- Closer to abacus
  - Passive register (memory) of states



"The human race will have a new kind of instrument which will increase the power of the mind much more than optical lenses strengthen the eyes… One could carry out the ***description of a machine***, no matter how complicated, in characters which would be merely the letters of the alphabet, and so provide the mind with a method of knowing the machine and all its parts." Leibniz, 1679.



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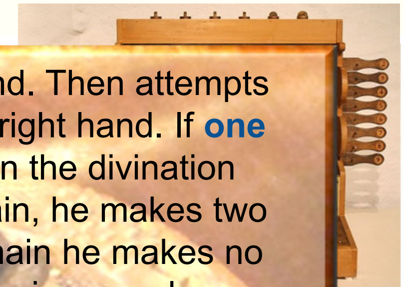
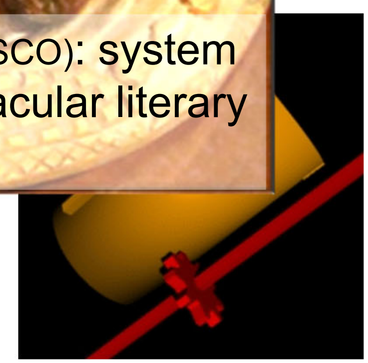
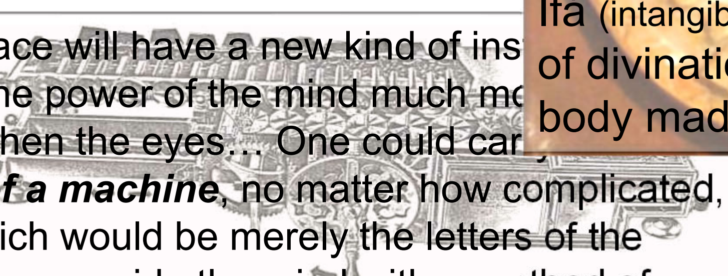


a priest holds six sacred palm nuts in his left hand. Then attempts to grab all of them out at the same time with his right hand. If **one** nut remains in his left hand , he makes a mark on the divination board which represents **a zero**. If **two** nuts remain, he makes two marks which represent **one**. If none or more remain he makes no marks at all. This is continued until four pairs of unique marks are left on the board which generate a 8-bit binary code.

Ifá (intangible cultural heritage of humanity by UNESCO): system of divination is a binary code to access oracular literary body made up of 256 volumes (signs).





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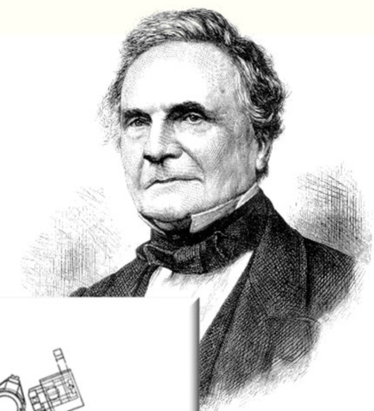
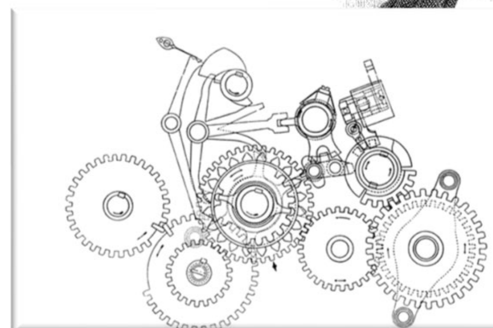
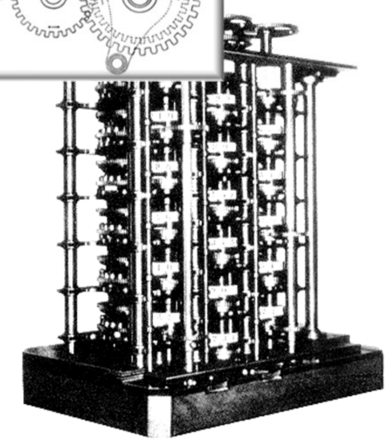
## Charles Babbage (1791 – 1871)

### difference engine

- Special-purpose digital computing machine for the **automatic** production of mathematical tables.
  - logarithm tables, tide tables, and astronomical tables
  - Steam-driven, consisted entirely of mechanical components - brass gear wheels, rods, ratchets, pinions, etc.
  - Numbers were represented in the decimal system by the positions of 10-toothed metal wheels mounted in columns.
- Never completed the full-scale machine
  - Completed several fragments. The largest is on display in the London Science Museum.  In 1990, it was built (London Science Museum)
- The Swedes Georg and Edvard Scheutz (father and son) constructed a modified version of Babbage's Difference Engine.
- For an interesting “what-if” scenario read “The Difference Engine” by Bruce Sterling and William Gibson







Not a universal Turing machine, but an analog computer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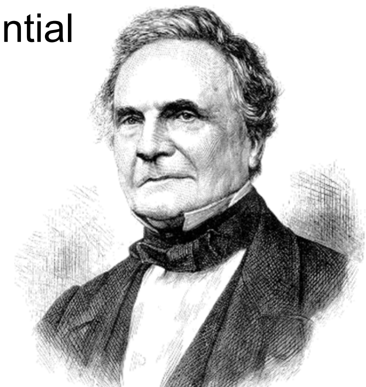
## The analytical engine had an “external tape”

Turing on programs (numbers as instructions) : “[Babbage] had all the essential ideas [and] planned such a machine, called the ***Analytical Engine***. […]



- general-purpose mechanical digital computer.
  - Separated **memory store** from a **central processing unit** (or ‘mill’)
  - able to select from among **alternative actions** consequent upon the outcome of its previous actions
    - Conditional branching: Choice, information
  - Mechanical cogs not just numbers
    - **Variables** (states/configurations)
- Programmable
  - Data and instructions on distinct **punched cards**

"It is only a question of cards and time, […] and there is no reason why (twenty thousand) cards should not be used if necessary, in an Analytical Engine for the purposes of the mathematician”. Henry Babbage (1888)

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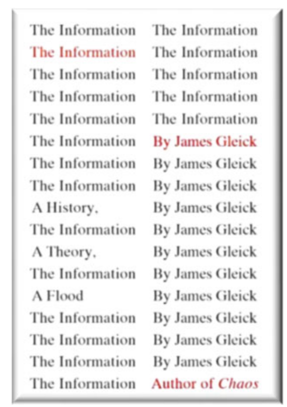
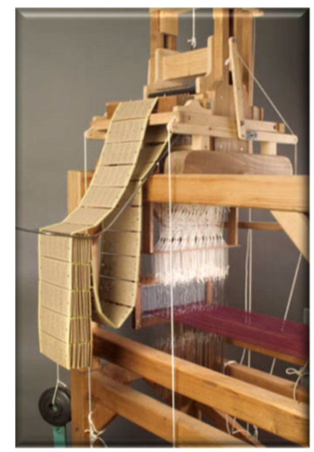
Charles Babbage (1791 – 1871) and Ada Lovelace (1815-1852)

The external tape as a general design principle (system) of universal computation

- Analytical engine
  - Separated **memory store** from a **central processing unit** (or 'mill')
  - Cogs not just numbers
    - **variables**
- Programmable
  - instructions on **punched cards**
    - Inspired by the Jacquard Loom
  - Ada Lovelace: the science of operations
    - Set of (recursive) rules for producing Bernoulli numbers (a program)
    - **Separation** of variable and operational (data) cards
    - would punch out cards for later use
      - "the Engine eating its own tail." (Babbage)



code

distinction between *numbers that mean things* and *numbers that do things*.

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## The external tape as a general design principle (system) of universal computation

- Analytical engine
  - Separated memo...
  - ...numb...
- ...
  - ...n pu...
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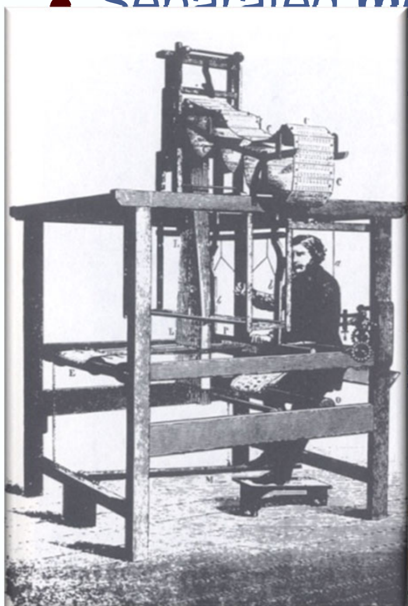
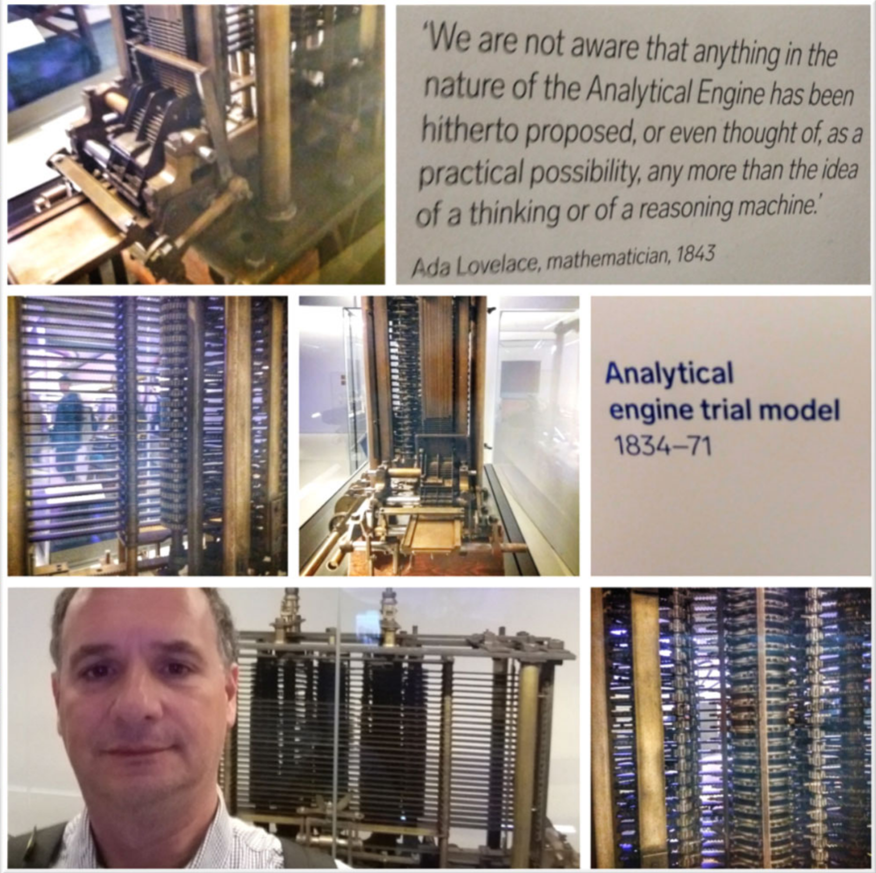
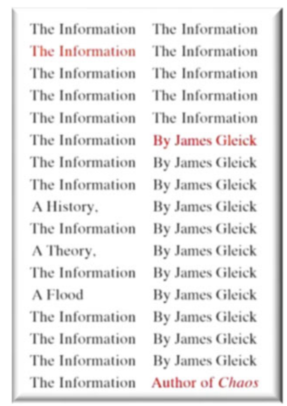
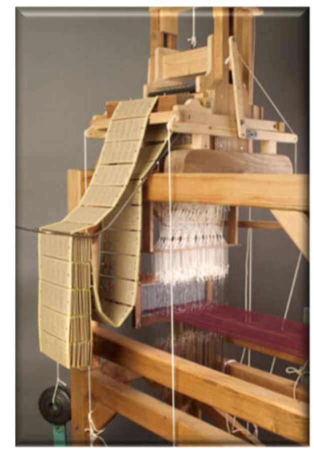
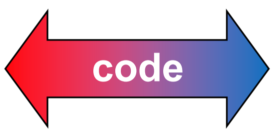
  - ...sive)...
  - ...of va...
  - ... out
  - ...ne eat








distinction between *numbers that mean things*
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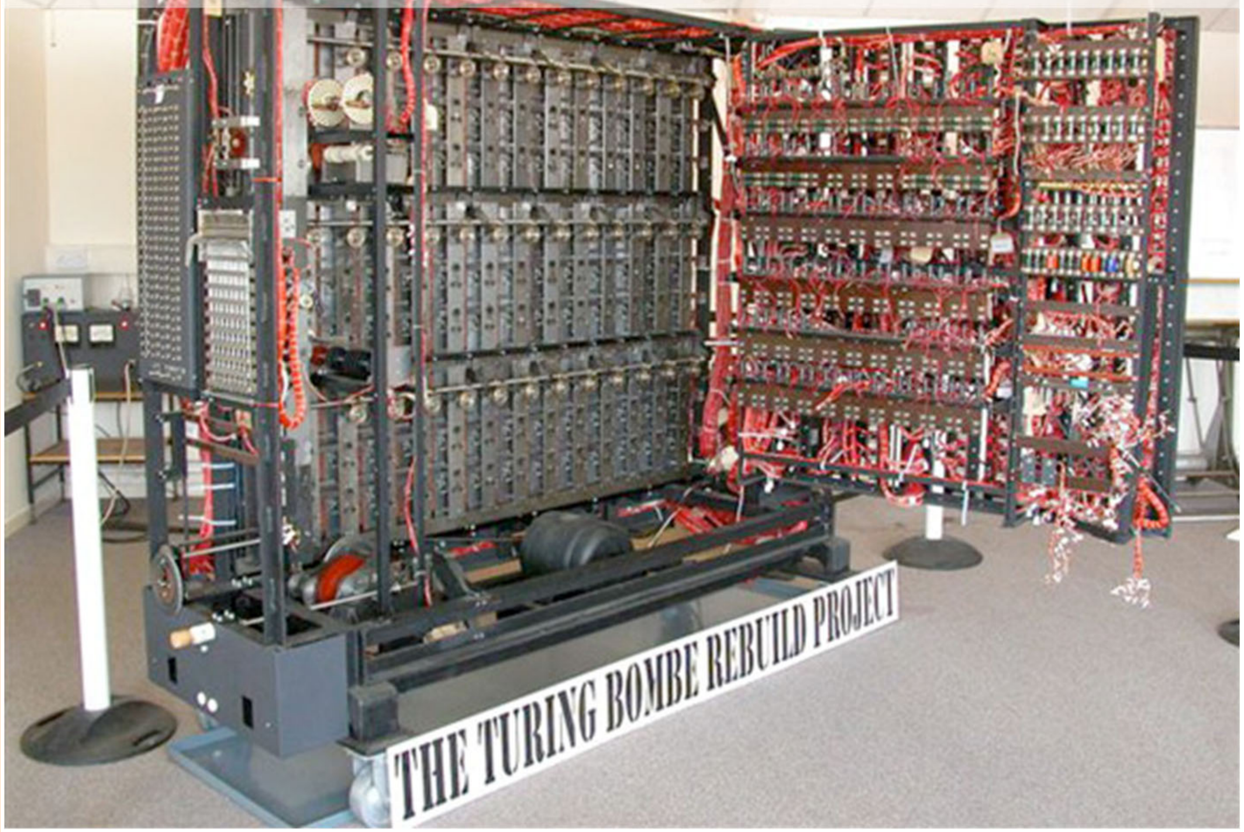
not electronic, not digital, not general-purpose

Turing bombe: Enigma Cracker at Bletchley Park (1940-1945)
Electro-mechanical, hundreds produced in UK and US

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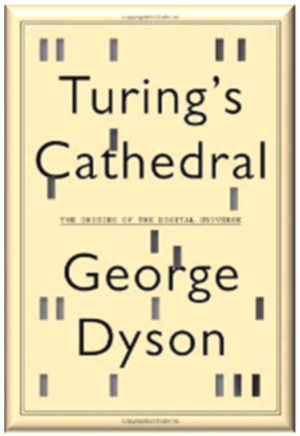
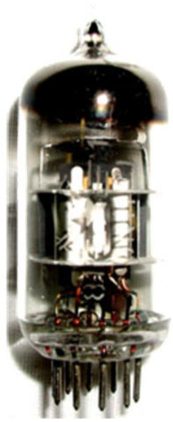
# ENIAC (1945)

Electronic Numerical Integrator And Computer



- First fully functioning electronic digital computer to be built in the U.S.
  - Electrical Numerical Integrator and Computer
  - University of Pennsylvania, for the Army Ordnance Department, by J. Presper Eckert and John Mauchly.
    - Far from general-purpose: The primary function was calculation of tables used in aiming artillery.
    - ENIAC was not a stored-program computer, and setting it up for a new job involved reconfiguring the machine by means of plugs and switches.
    - Used decimal digits instead of binary ones
    - Nearly 18,000 ***vacuum tubes for switching.***
      - Storage of all those vacuum tubes and the machinery required to keep the cool took up over 167 square meters (1800 square feet) of floor space.
      - invented by American physicist Lee De Forest in 1906.
      - worked by using large amounts of electricity to heat a filament inside the tube. the presence of current represented a one.
    - punched-card input and output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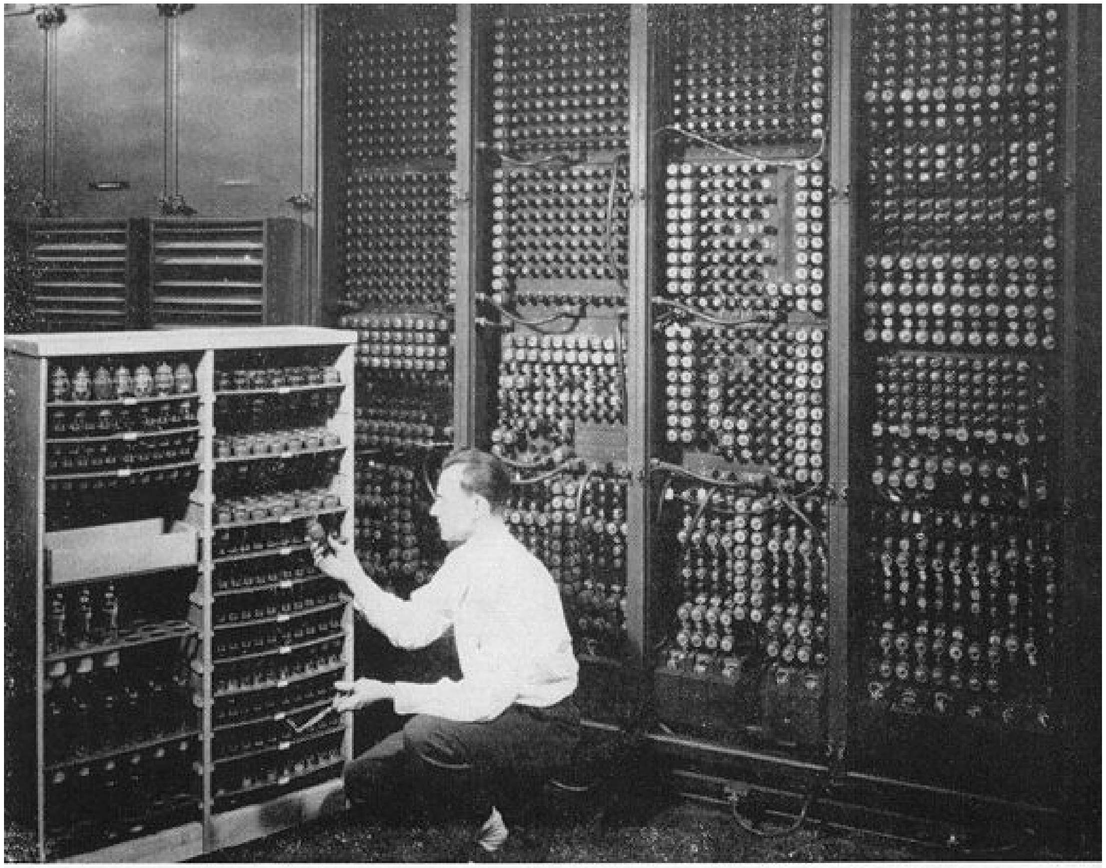
# ENIAC (1945)

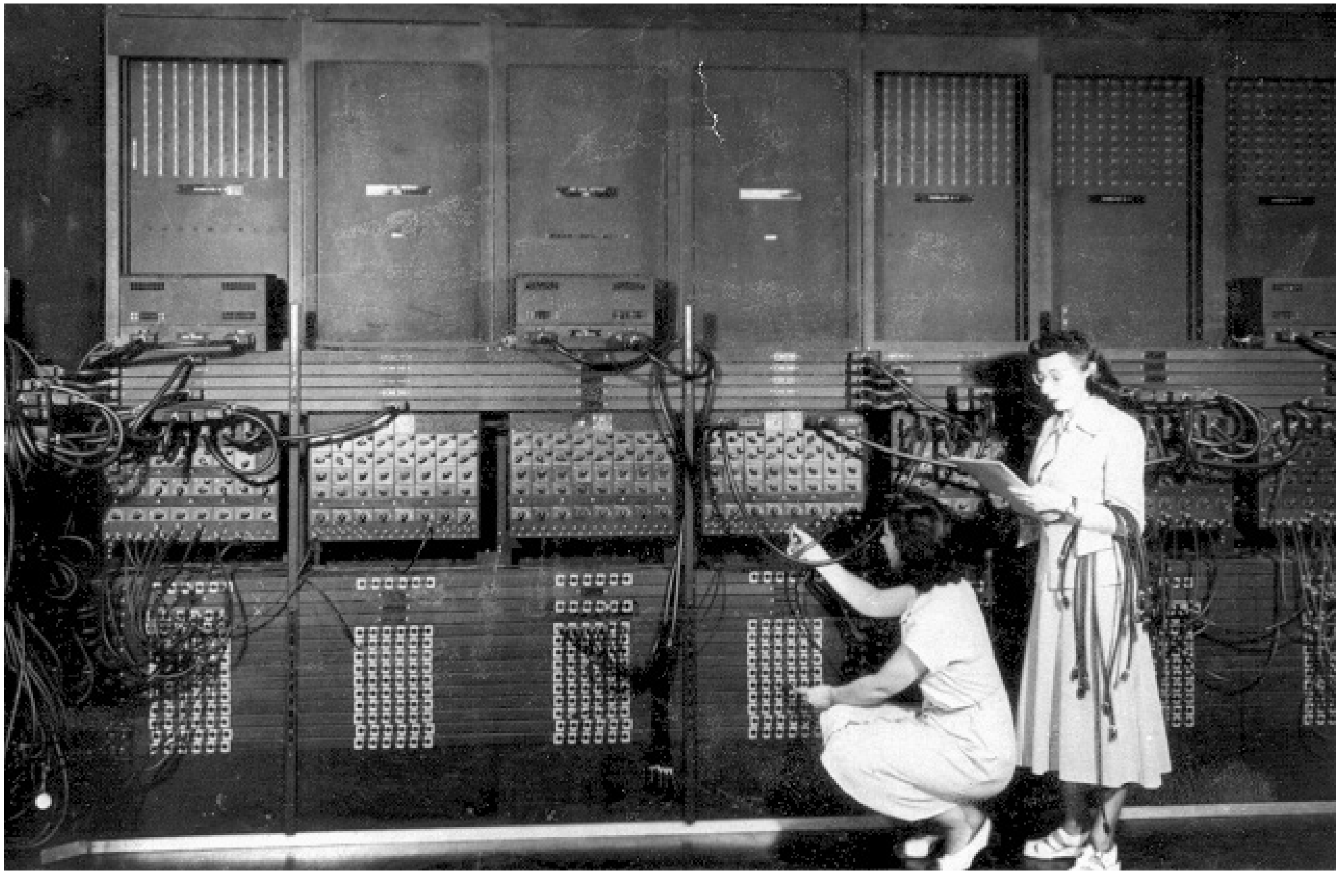
Electronic Numerical Integrator And Computer (decimal)



Replacing a bad tube meant checking among ENIAC's 19,000 possibilities.

# ENIAC (1945)

Electronic Numerical Integrator And Computer



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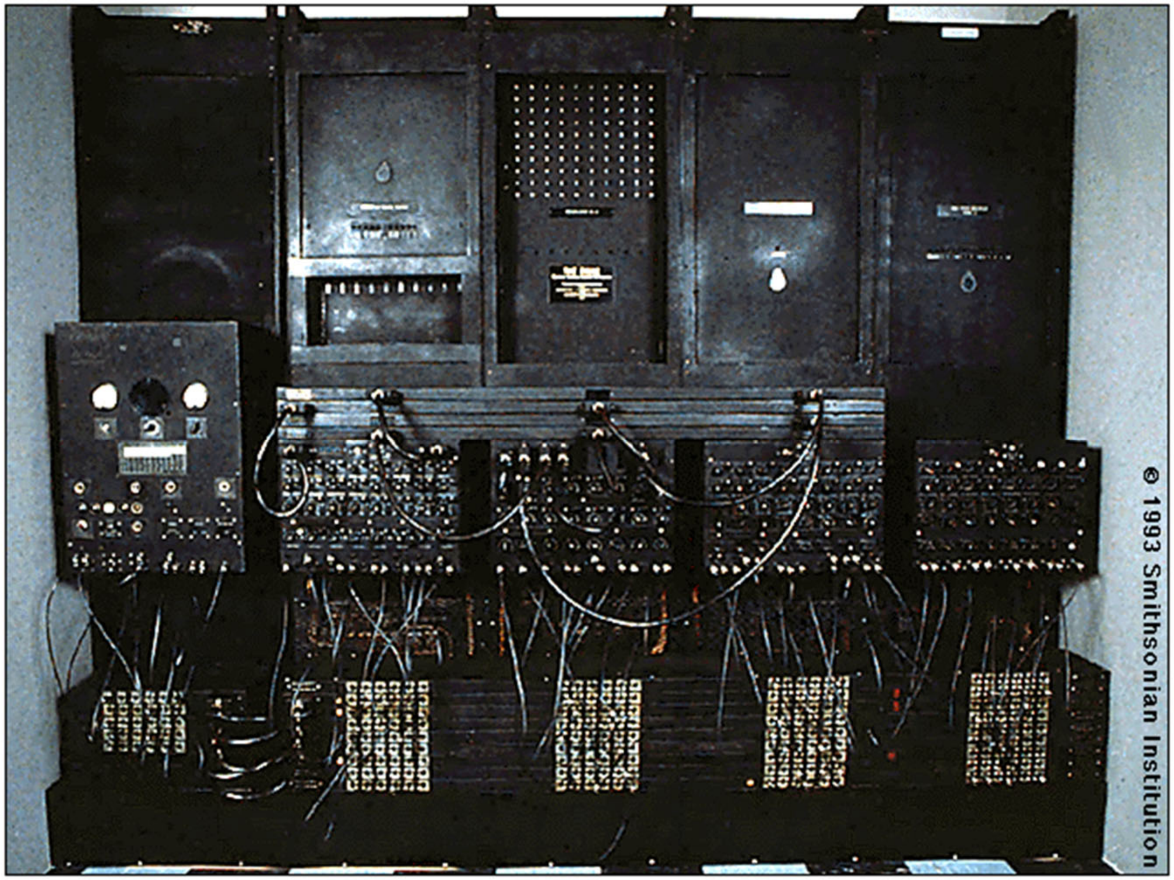
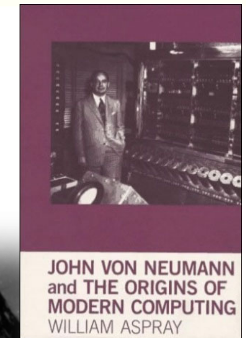
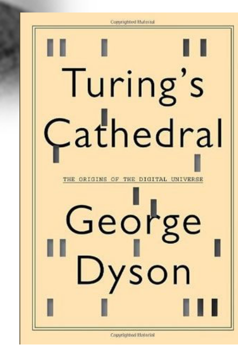


## Turing machines beyond the decision problem

" 'Words' coding the orders are handled in the memory just like numbers" --- distinction between *numbers that mean things* and *numbers that do things*.

- realizing the power of Turing's tape
  - physical (electronic) computers
  - emphasized the importance of the ***stored-program computer*** concept (the external tape)
    - EDVAC (1951), IAS Machine (1952) - binary
  - allows machine to modify its own program
    - von Neumann architecture: The functional **separation** of storage from the processing unit.
      - programs can exist as data (two roles)
    - Converts tape to fixed-address memory (random-access memory)
  - Ultimate ***general-purpose*** machines




"Let the whole outside world consist of a long paper tape".
—John von Neumann, 1948

## Turing machines beyond the decision problem

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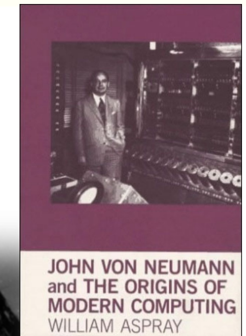
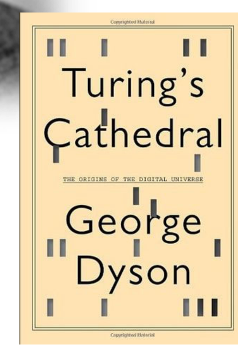
  - Ultimate ***general-purpose*** machines

"Since Babbage's machine was not electrical, and since all digital computers are in a sense equivalent, we see that this use of electricity cannot be of theoretical importance.… The feature of using electricity is thus seen to be only a very superficial similarity." (Alan Turing)

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# IAS Machine (1952)

electronic digital (stored-program) computer with 40 bit word (IAS, Princeton)

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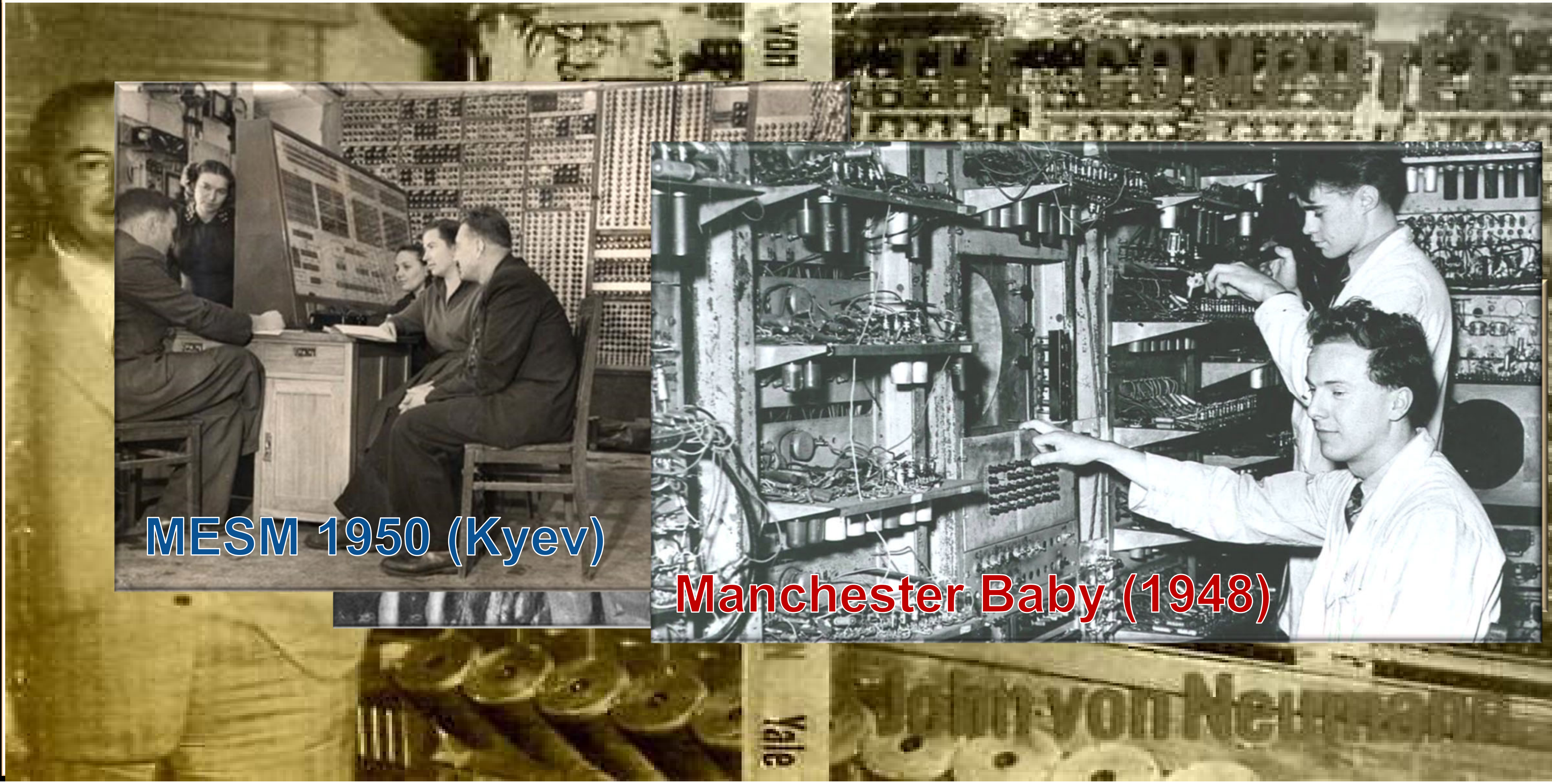
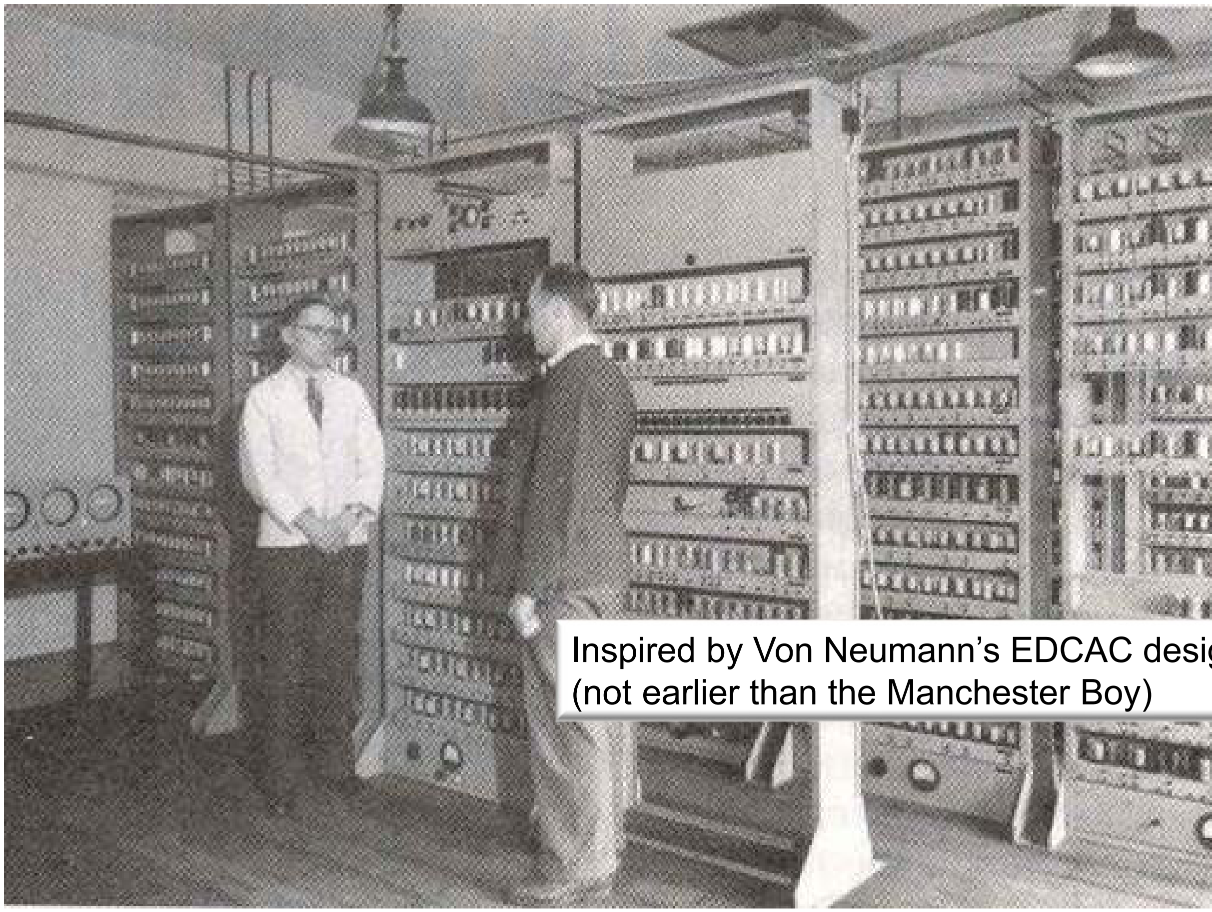
electronic digital (stored-program) computer with 40 bit word (IAS, Princeton)



# EDSAC (1949)

Electronic Delay Storage Automatic Calculator (Cambridge)



Inspired by Von Neumann's EDCAC design, but built earlier (not earlier than the Manchester Boy)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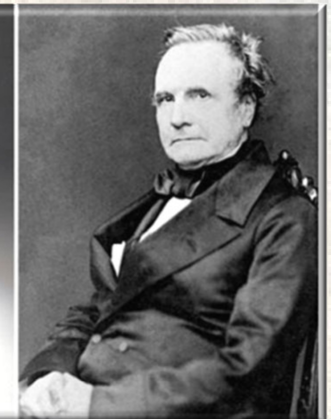
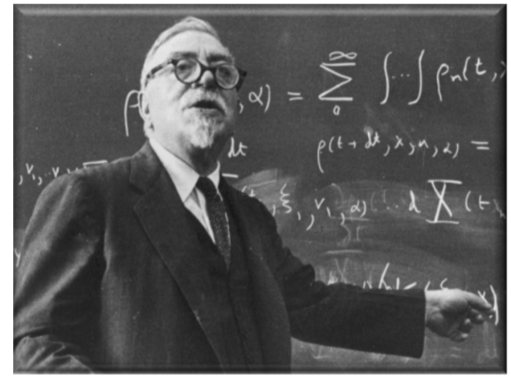
Babbage/Lovelace first to try to build it (before Turing)

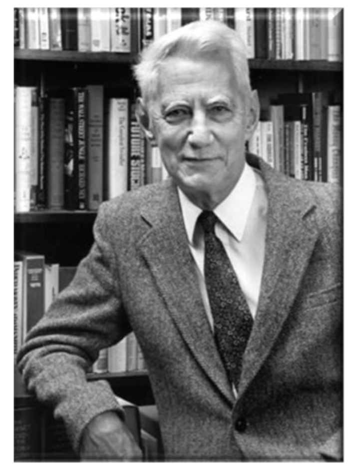


distinction between *numbers that mean things*
and *numbers that (do things) move matter*

readings

- Class Book
  - Klir, G.J. [2001]. *Facets of systems science*. Springer.
- Papers and other materials
  - Reading and Discussion Group 1
    - Negin Esmaeili, Amahury Lopez Diaz et al :
      - Heims, S.G. [1991]. *The Cybernetics Group*. MIT Press. Chapters: 1 - 2.
        - Optional: Chapters 11-12.
        - Optional: McCulloch, W. and W. Pitts [1943], "A Logical Calculus of Ideas Immanent in Nervous Activity". *Bulletin of Mathematical Biophysics* **5**:115-133.
      - Gleick, J. [2011]. *The Information: A History, a Theory, a Flood*. Random House. Chapter 8.
        - Optional: Prokopenko, Mikhail, Fabio Boschetti, and Alex J. Ryan. "An information theoretic primer on complexity, self-organization, and emergence." *Complexity* **15**.1 (2009): 11-28.
        - Kline, Ronald R [2015]. *The cybernetics moment, or, why we call our age the information age*. Johns Hopkins University Press. Chapters 1-2.



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key events coming up

- Paper Presentation: 20%
  - Present (501) and lead (501&440) the discussion of an article related to the class materials
  - *section 01* presents in class, *section 20* (Enginet) posts videos on Brightspace (exceptions possible)
- Module 1: Cybernetics and the Information Turn
- Thursday, August 31st
  - Reading and Discussion Group 1
    - Negin Esmaeili, Amahury Lopez Diaz et al :
      - Heims, S.G. [1991]. *The Cybernetics Group*. MIT Press. Chapters: 1 - 2.
        - Optional: Chapters 11-12.
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        - Kline, Ronald R [2015]. *The cybernetics moment, or, why we call our age the information age*. Johns Hopkins University Press. Chapters 1-2.
    - **Discussion by all**
- **No Class Tuesday, September 5th**

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## more upcoming readings (check brightspace)

- Paper Presentation: 20%
  - Present (501) and lead (501&440) the discussion of an article related to the class materials
    - Enginet students post/send video or join by Zoom synchronously
- Tuesday, September 12th
  - Reading and Discussion Group 2
    - Savannah Sidoti, Akshay Gangadhar, et al
      - Brenner, Sydney. [2012]. "History of Science. The Revolution in the Life Sciences". *Science* **338** (6113): 1427-8.
      - Brenner, Sydney. [2012]. "Turing centenary: Life's code script. *Nature* **482** (7386) (February 22): 461-461.
      - Cobb, Matthew. [2013]. "1953: When Genes Became 'Information'." *Cell* **153** (3): 503-506.
        - Optional: Searls, David B. [2010]. "The Roots of Bioinformatics". *PLoS Computational Biology* **6**(6): e1000809.
      - Weaver, W. [1948]. "Science and Complexity". *American Scientist*, **36**(4): 536-44. Also available in Klir, G.J. [2001]. *Facets of systems Science*. Springer, pp: 533-540.
- Future Modules
  - See brightspace

# evaluation

- Participation: 20%.
  - class discussion, everybody reads and discusses every paper
  - engagement in class, including online
- Paper Presentation and Discussion: 20%
  - All students are assigned to a Reading and Discussion Group
  - **SSIE501** students in group present and discuss papers
    - all students are supposed to read and participate in discussion of every paper.
    - *section 01 groups* present in class, *section 20 groups* present via zoom or sends a videos
  - Presenter group prepares short summary of assigned paper (15 minutes)
    - no formal presentations or PowerPoint unless figures are indispensable.
  - Summary should:
    - 1) Identify the key goals of the paper (not go in detail over every section)
    - 2) What discussant liked and did not like
    - 3) What authors achieved and did not
    - 4) Any other relevant connections to other class readings and beyond.
  - **ISE440** students in group participate as lead discussants
    - not to present the paper, but to comment on points 2-3) above
  - Class discussion is opened to all
    - lead discussant ensures important paper contributions and failures are addressed
- Black Box: 60%
  - Group Project (2 parts)
    - Assignment I (25%) and Assignment II (35%)


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# more upcoming readings (check brightspace)

- Paper Presentation: 20%
  - Present (501) and lead (501&440) the c
    - Enginet students post/send video or join
- Module 2: Systems Science
  - Reading and Discussion Group 3 (
    - Sarah Donovan, Nicole Dates, et al:
      - Klir, G.J. [2001]. *Facets of systems S*
        - Optional:
        - Rosen, R. [1986]. "Some comr Klir, G.J. [2001]. *Facets of sys*
        - Wigner, E.P. [1960], "The unre mathematical sciences deliver
      - Klir, G.J. [2001]. *Facets of systems S*
  - Reading and Discussion Group 4
    - Emma Bachyrycz, et al:
      - Klir, G.J. [2001]. *Facets of systems S*
        - Optional: Klir, G.J. [2001]. *Fac*
      - Schuster, P. (2016). The end of Moo *Complexity*. **21**(S1): 6-9. DOI 10.100
      - Von Foerster, H., P. M. Mora and L. 5.
- Future Modules
  - See brightspace