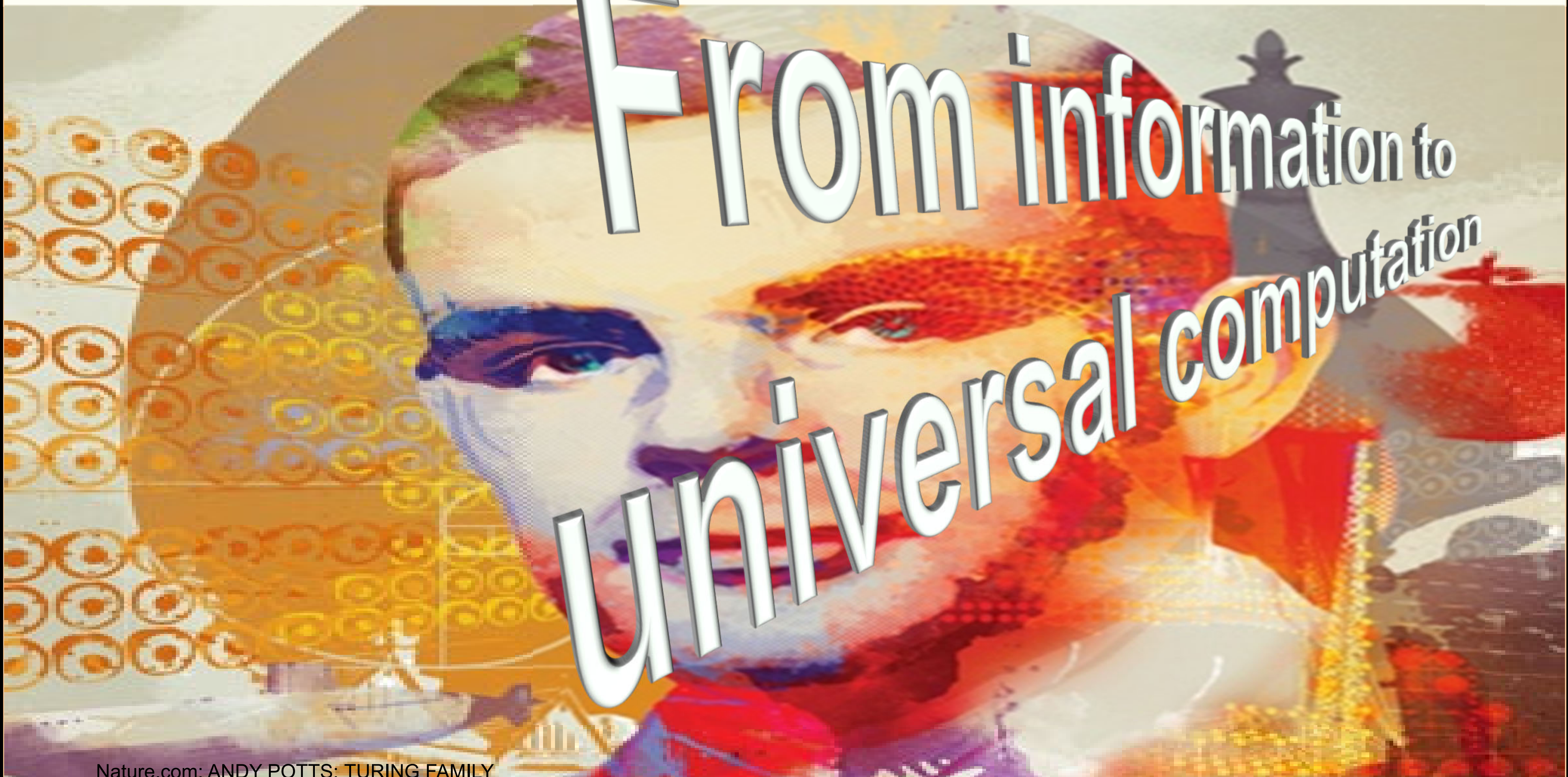
introduction to systems science

lecture 3

From information to universal computation



Nature.com; ANDY POTTS; TURING FAMILY

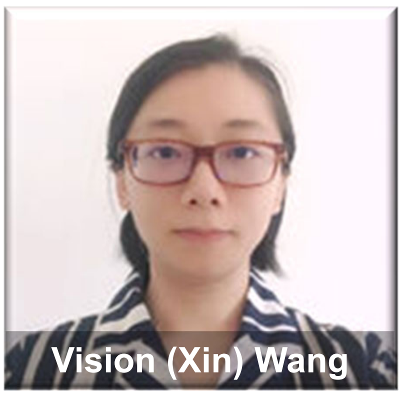
Resources

- web page
  - casci.binghamton.edu/academics/ssie501
- online class
  - binghamton.zoom.us/j/93351260610
- blog: sciber
  - sciber.blogspot.com
- Brightspace
  - brightspace.binghamton.edu/d2l/home/255004

SSIE-501/ISE-440 - Fall 2022

luis m. rocha

office hours:
Tuesdays 9:00- 11:30am
binghamton.zoom.us/my/luismrocha



office hours:
Tuesdays 4-5pm, Wednesdays 12:30-2:30pm,
Thursdays 9:00-11:00am, EB-K1
binghamton.zoom.us/j/5483243323

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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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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.
        - 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.
    - **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

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
- Module 2: Systems Science
  - Reading and Discussion Group 3 (Enginet)
    - Sarah Donovan, Nicole Dates, et al:
      - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapters 1 and 2.
        - Optional:
        - Rosen, R. [1986]. "Some comments on systems and system theory". *Int. J. of General Systems*, **13**: 1-3. Available in: Klir, G.J. [2001]. *Facets of systems Science*. Springer. pp: 241-243.
        - Wigner, E.P. [1960], "The unreasonable effectiveness of mathematics in the natural sciences". Richard courant lecture in mathematical sciences delivered at New York University, May 11, 1959. *Comm. Pure Appl. Math*, **13**: 1-14.
      - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 3.
  - Reading and Discussion Group 4
    - Emma Bachyrycz, et al:
      - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 8.
        - Optional: Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 11
      - Schuster, P. (2016). The end of Moore's law: Living without an exponential increase in the efficiency of computational facilities. *Complexity*. **21**(S1): 6-9. DOI 10.1002/cplx.21824.
      - Von Foerster, H., P. M. Mora and L. W. Amiot [1960]. "Doomsday: Friday, November 13, AD 2026." Science **132**(3436):1291-5.
- Future Modules
  - See brightspace

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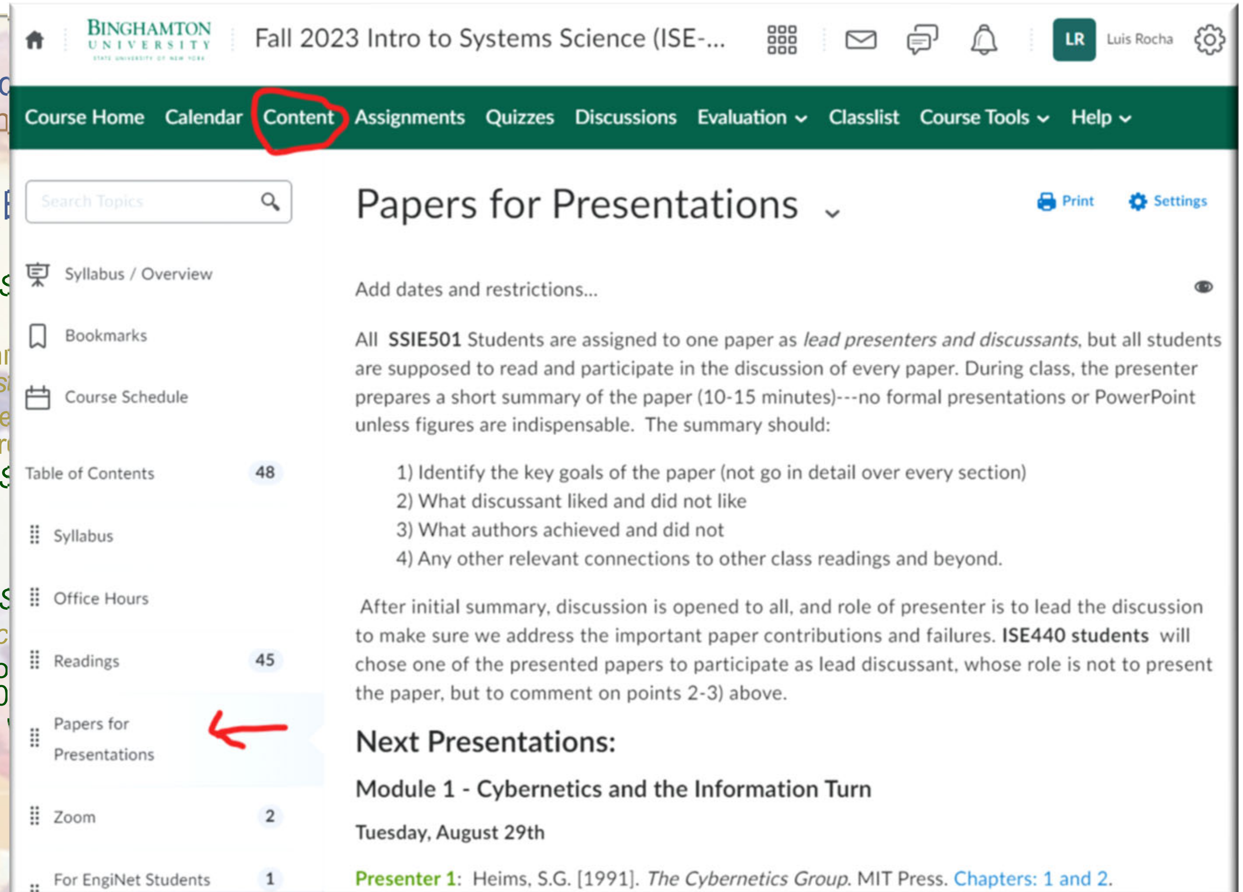
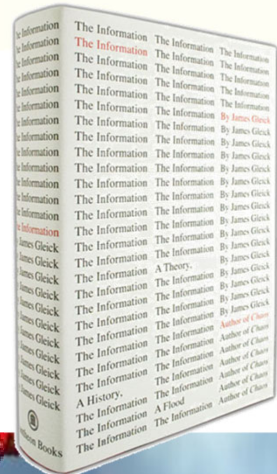
        - Optional: Klir, G.J. [2001]. *Fac*
      - Schuster, P. (2016). The end of Moo *Complexity*. **21**(S1): 6-9. DOI 10.100
      - Von Foerster, H., P. M. Mora and L. 5.
- Future Modules
  - See brightspace



rate of removing uncertainty of each symbol



Holdin' me back
Gravity's holdin' me back
I want you to hold out the palm of your hand
Why don't we leave it at that?
Nothin' to say
When everything gets in the way
Seems you cannot be replaced
And I'm the one who will stay, oh

“syntactic” surprise But what about function and meaning (semantics)?

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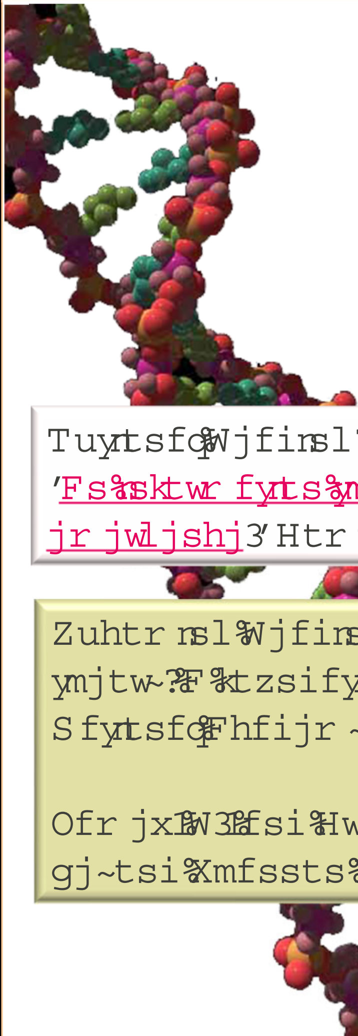
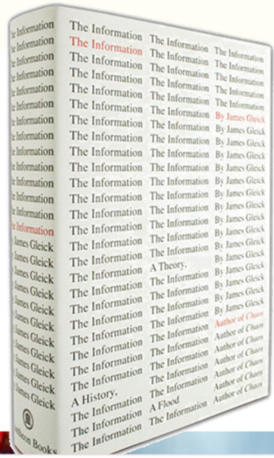
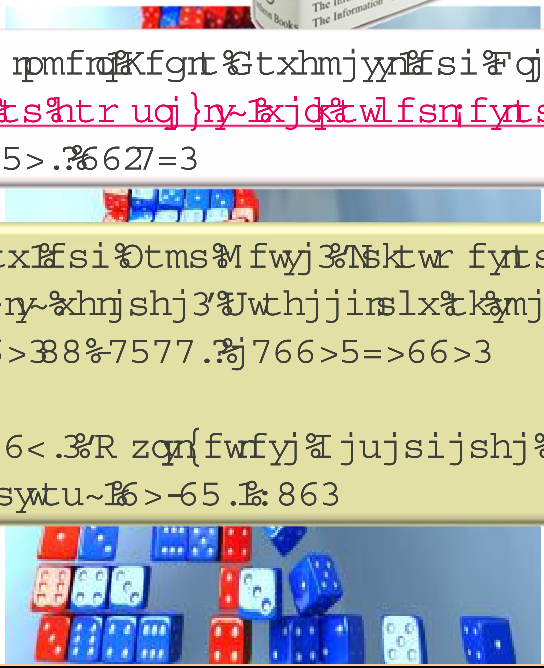
rate of removing uncertainty of each symbol







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How did we get here?
MEDIA
NETWORK SEARCH
WORLD
BUSINESS

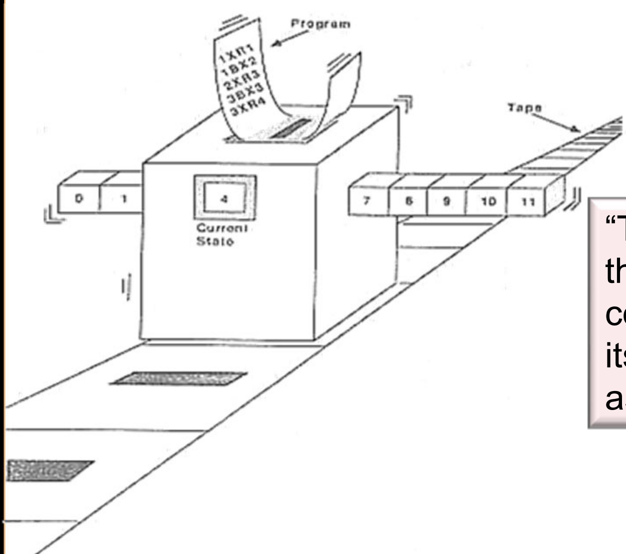
key contributions (most relevant to biocomplexity)

- “The chemical basis of morphogenesis”
  - Turing, A. M. *Phil. Trans. R. Soc. Lond. B* **237**, 37–72 (1952).
    - Reaction-diffusion systems
- “Computing machinery and intelligence”
  - Turing, A. M. *Mind* **49**, 433–460 (1950).
    - The “Turing Test”
- “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

Brenner, Sydney. [2012]. “Life’s code script.” *Nature* **482** (7386): 461-461.

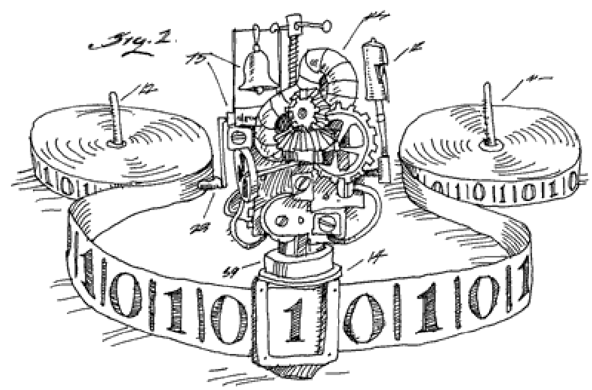
A fundamental principle of computation

- "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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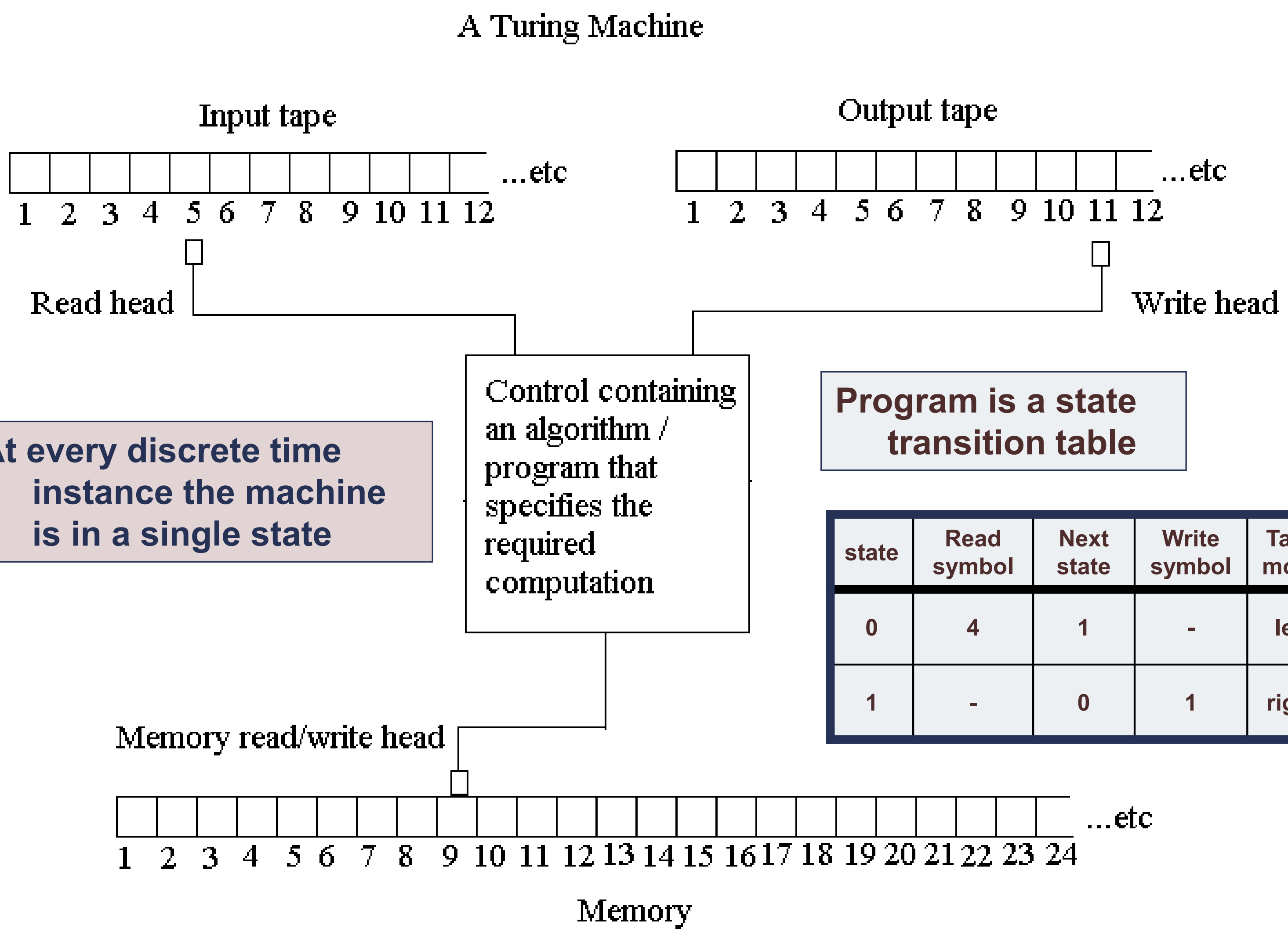
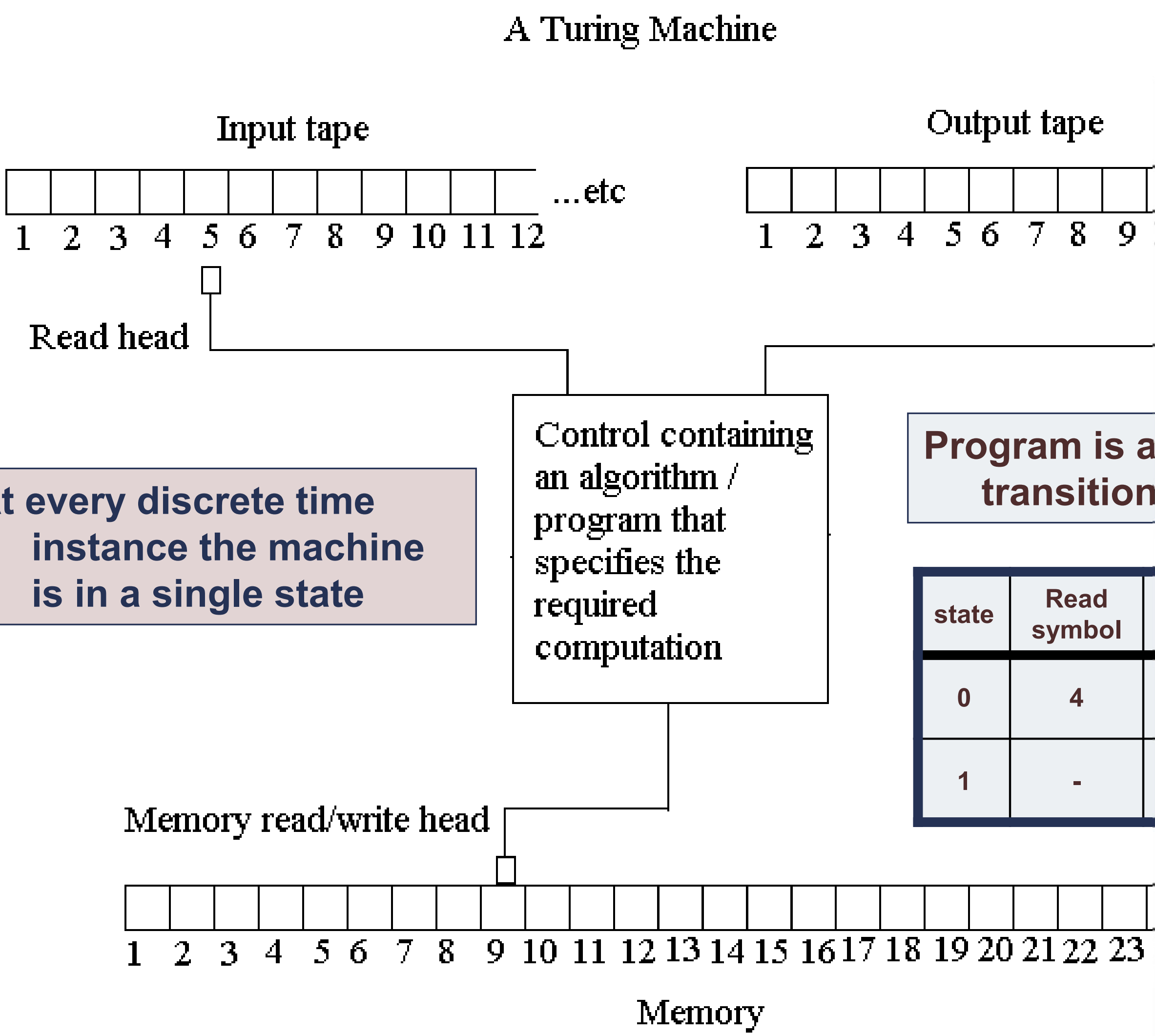


At every discrete time instance the machine is in a single state

Program is a state transition table

state	Read symbol	Next state	Write symbol	Tape move
0	4	1	-	left
1	-	0	1	right



At every discrete time instance the machine is in a single state

Program is a transition

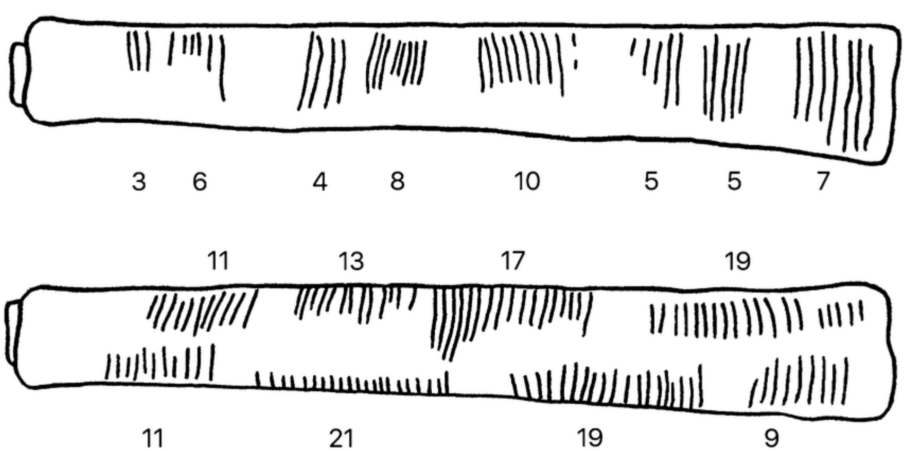
state	Read symbol
0	4
1	-

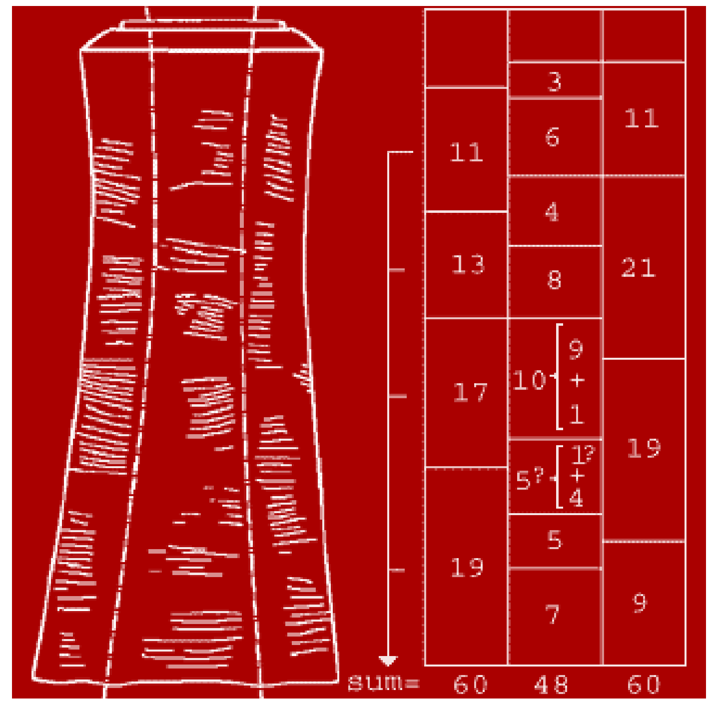
where do numbers come from?

- Number Perception
  - Recognition of a discrete quantity of objects distinct from a continuous quantity
    - Exists even in animals, birds, and insects
- Counting
  - A measurement process from a physical system to a symbol
    - E.g. notches on a bone
    - First symbols were probably numbers
- ***Lebombo bone***
  - Oldest counting tool is a piece of baboon fibula with 29 notches from 35,000 BC, discovered in the mountains between South Africa and Swaziland
    - Probably representing the number of days in a Moon Cycle
  - "Wolf Bone" from Czech Republic
    - with 55 notches in groups of 5, from 30,000 BC.

earliest examples

- The ***Ishango Bone***
  - Oldest Mathematical Artefact?
    - 20,000 BC, border of Zaire and Uganda
  - Used as a counting tool?
    - 9,11,13,17,19, 21: odd numbers
    - 11, 13, 17, 19: prime numbers
    - 60 and 48 are multiples of 12





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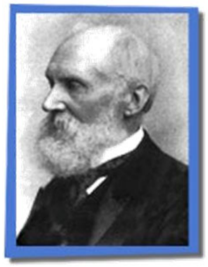
abstracting symbol mappings

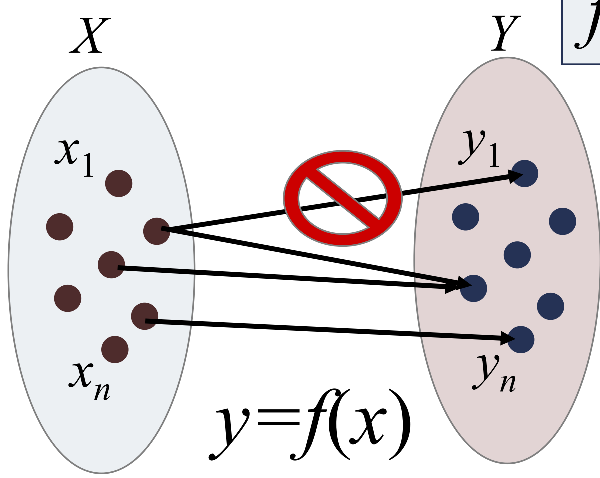
- Counting
  - A measurement process from a physical system to a symbol
    - A mapping between discrete objects and symbols
    - First numbers were not completely abstract
      - Specific attributes of concrete objects
- Computation
  - Abstract concept of one-to-one pairing of symbols
  - Mathematical concept of ***function***
- Formalization
  - To completely abstract away the significance of measuring observables from real objects

"*When you can measure what you are speaking of and express it in numbers you know that on which you are discoursing. But if you cannot measure it and express it in numbers. your knowledge is of a very meagre and unsatisfactory kind*". Lord Kelvin



producing symbols from symbols

$$f : X \rightarrow Y$$



Function: a complete and unambiguous mapping between sets of symbols

Computation: automatic process or method of implementing a function

Leibniz introduced the word in 1694

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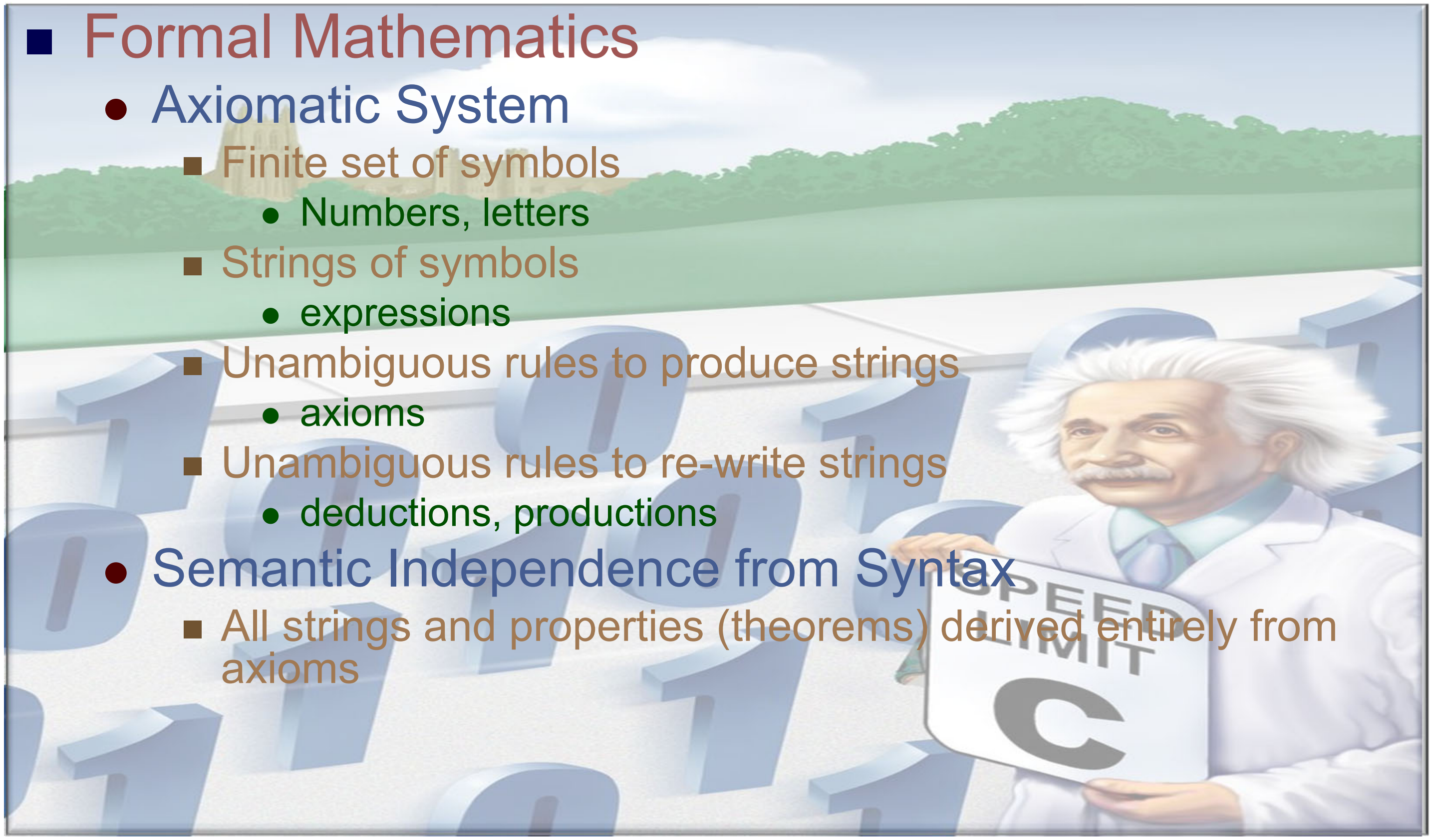
abstracting symbol mappings

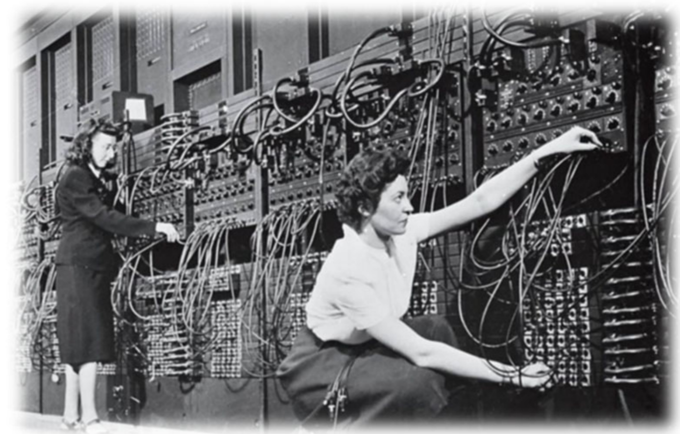


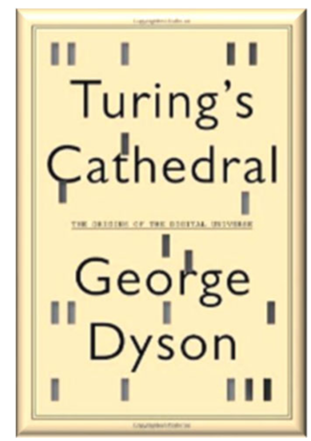
- **Formal Mathematics**
  - Axiomatic System
    - Finite set of symbols
      - Numbers, letters
    - Strings of symbols
      - expressions
    - Unambiguous rules to produce strings
      - axioms
    - Unambiguous rules to re-write strings
      - deductions, productions
  - Semantic Independence from Syntax
    - All strings and properties (theorems) derived entirely from axioms

"*Insofar as the propositions of mathematics are certain they do not refer to reality; and insofar as they refer to reality, they are not certain*". Albert Einstein

from mathematical generality to physical implementation constraints

- Process of rewriting strings in a formal system according to a program of rules
  - Operations and states are syntactic
  - Symbols follow syntactical rules
  - Rate of computation is irrelevant
    - Program determines result, not speed of machine
  - Physical implementation is irrelevant for result
- Computer
  - **Physical device** that can reliably execute/approximate a formal computation
    - Errors always exist
    - Design aims to make **rate** and **dynamics** irrelevantD





"[…] essential elements in the machine are of a binary […] nature. Those whose state is determined by their history and are time-stable are memory elements. Elements of which the state is determined essentially by the existing amplitude of a voltage or signal are called 'gates'". Bigelow et al, 1947

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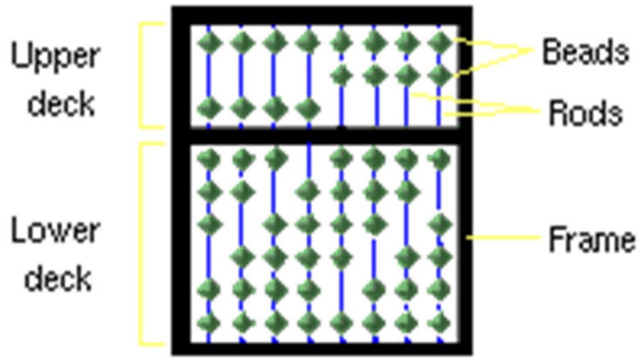
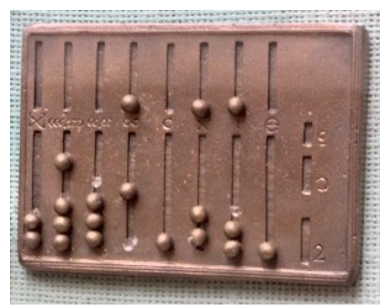
- ## Abacus
  - A counting aid, may have been invented in Babylonia in the fourth century B.C.
    - Not automatic: memory aid for intermediate calculations
  - Very used in China and Japan
    - Each bead on the upper deck has a value of 5,
    - Each bead on the lower deck has value of 1
      - Beads are considered counted, when moved towards the beam that separates the two decks.





Reconstruction of a Roman abacus in the *Cabinet des Médailles, Bibliothèque nationale*, Paris.

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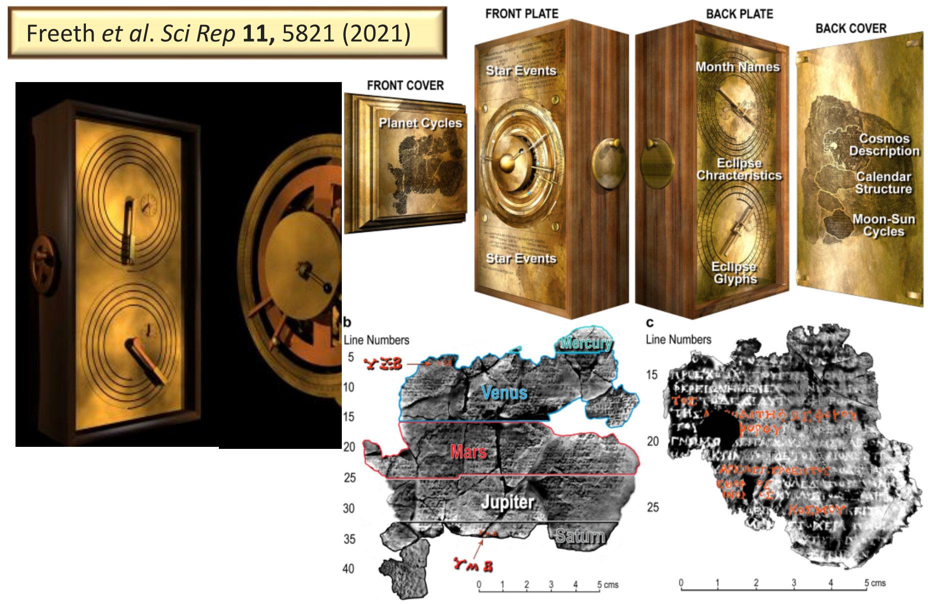
2,000-year-old astronomical calculator

- bronze mechanical **analog** computer
  - discovered more than 100 years ago in a Roman shipwreck, was used by ancient Greeks to display astronomical cycles.
- built around the end of the second century BC to calculate astronomical positions
- With imaging and high-resolution X-ray tomography to study how it worked.
  - complicated arrangement of at least 30 precision, hand-cut bronze gears housed inside a wooden case covered in inscriptions.
  - technically more complex than any known device for at least a millennium afterwards.

Not a universal Turing machine, but an analog computer

Freeth *et al*. *Sci Rep* **11,** 5821 (2021)



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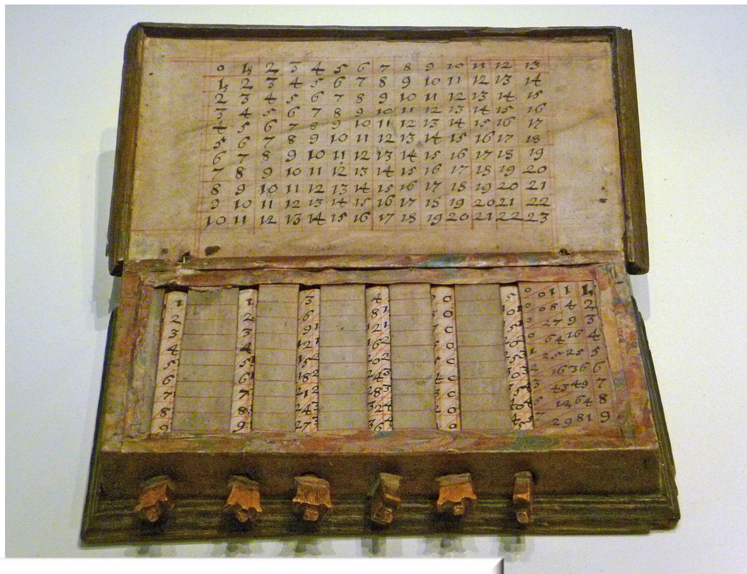
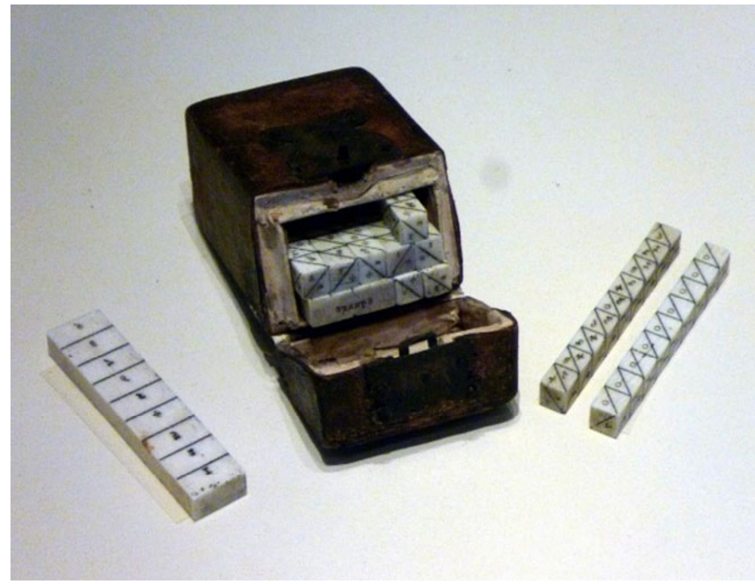
are people (and tables) too!

need to efficiently compute numerical tables, used in math, ballistics, astronomy, etc.





mechanical calculators to replace painstaking and error-prone human calculator work

Briggs (1561-1630): decimal algorithm, logs of 30,000 numbers to 14 decimal places and logs/tans of 1/100 of every degree, 14 decimal places

John Napier's (1550-1617)
- 1614: logarithm, "bones" and tables convert multiplication/division to addition/subtraction

are people (and tables) too!

need to efficiently compute numerical tables, used in math, ballistics, astronomy, etc.

Gr. 9

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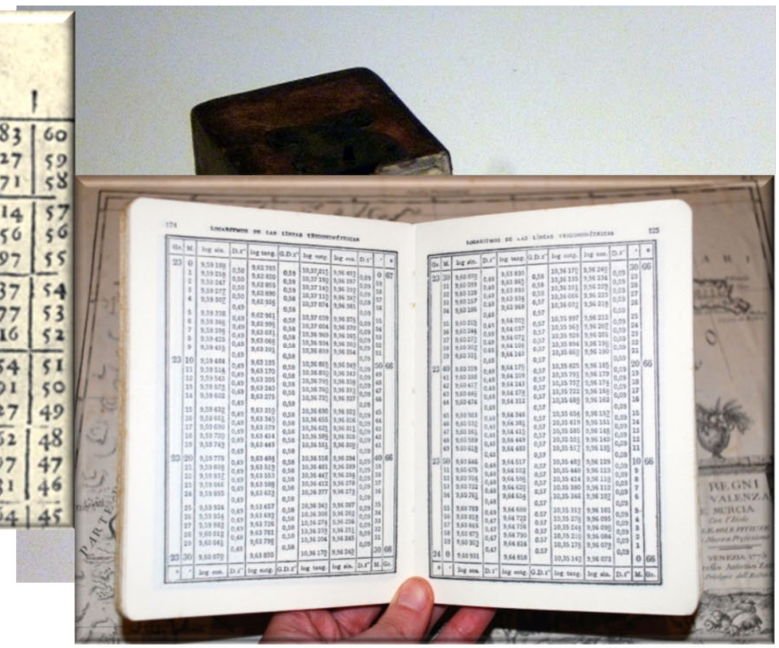
2	1570091	18514511	18389707	124804	9875971	58
3	1572964	18496231	18370964	125267	9875514	57
4	1575837	18477984	18352253	125731	9875056	56
5	1578709	18459772	18333576	126196	9874597	55
6	1581581	18441594	18314933	126661	9874137	54
7	1584453	18423451	18296324	127127	9873677	53
8	1587325	18405341	18277747	127594	9873216	52
9	1590197	18387265	18259203	128062	9872754	51
10	1593069	18369223	18240692	128531	9872291	50
11	1595941	18351214	18222213	129001	9871827	49
12	1598812	18333237	18203765	129472	9871362	48
13	1601684	18315294	18185351	129943	9870897	47
14	1604555	18297384	18166969	130415	9870431	46
15	1607426	18279507	18148619	130888	9869964	45



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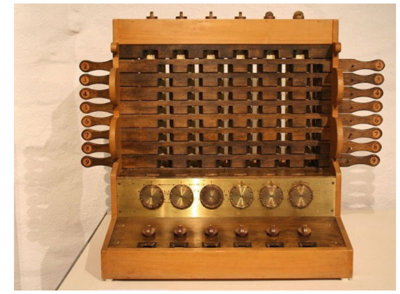
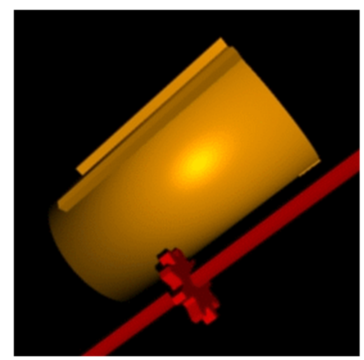
John Napier's (1550-1617)
- 1614: logarithm, "bones" and tables convert multiplication/division to addition/subtraction

Forefathers of the modern computer

- 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
- 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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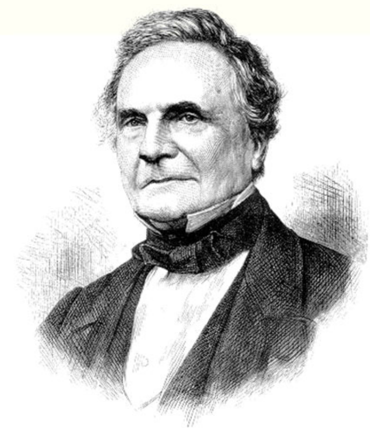
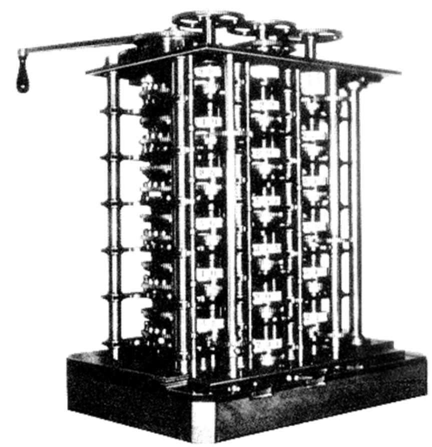
Difference engine



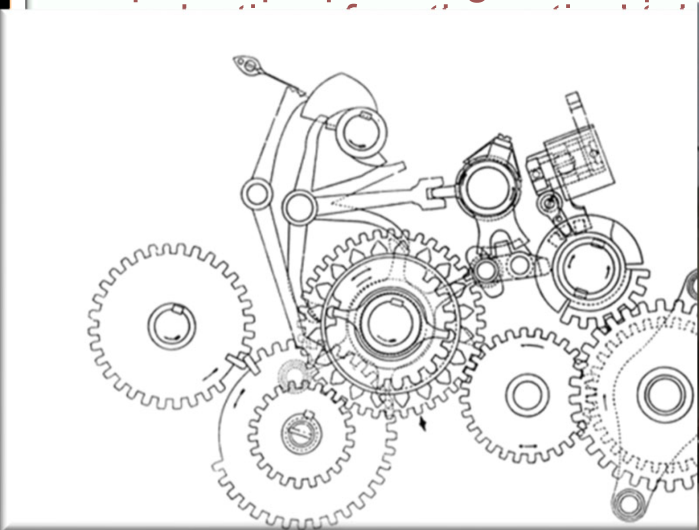
- Special-purpose digital computing machine for the **automatic** production of mathematical tables.
  - logarithm tables, tide tables, and astronomical tables
  - Steam-driven, consisted entirely of mechanical components - brass gear wheels, rods, ratchets, pinions, etc.
  - Numbers were represented 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

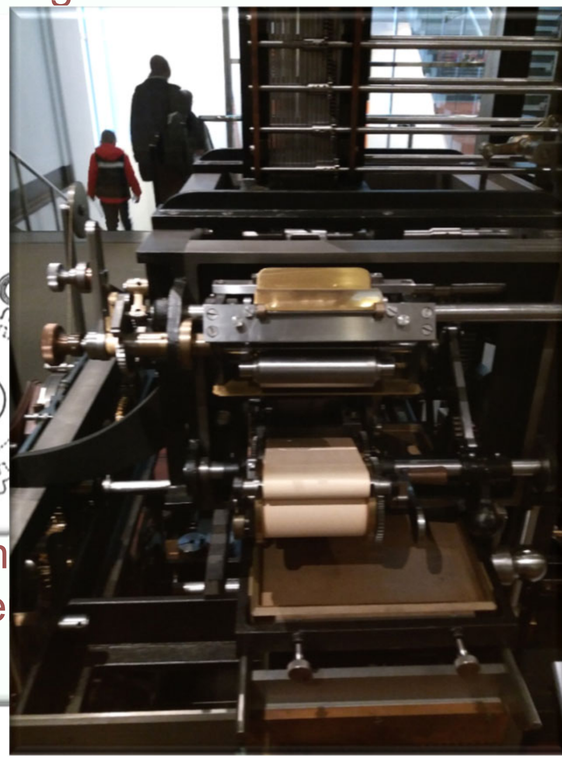
Not a universal Turing machine, but an analog computer

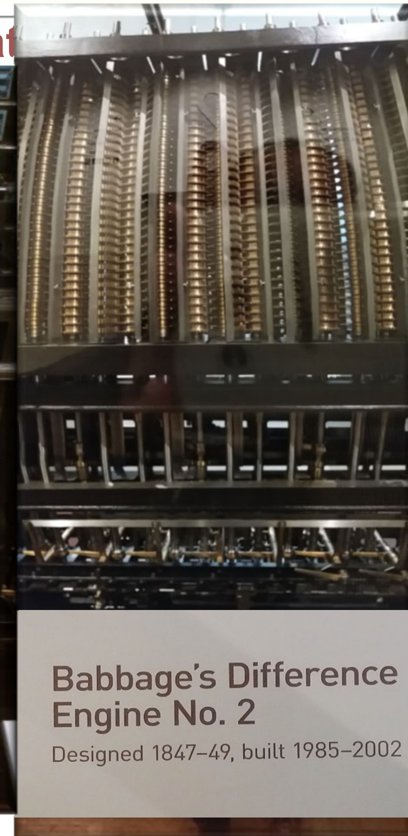


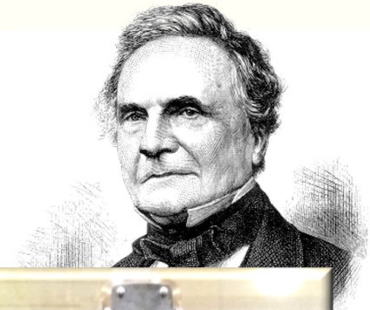
Difference engine

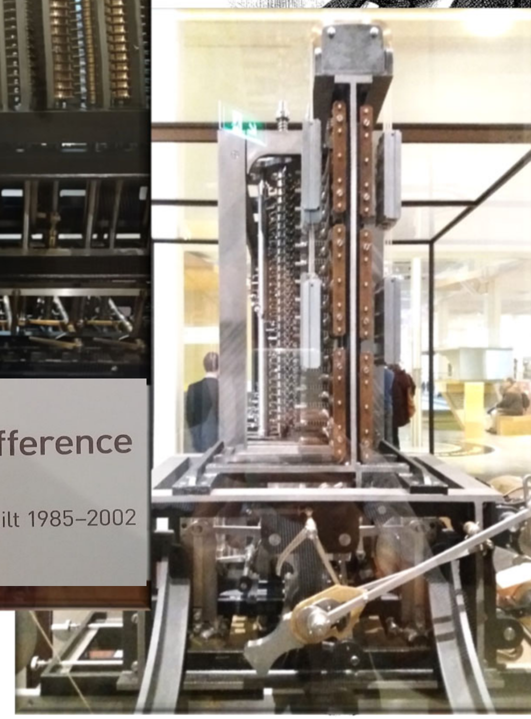
- Special-purpose digital computing machine for the **automat**











constructed a modified version

- For an interesting "what-if" sce
Engine" by Bruce Sterling and

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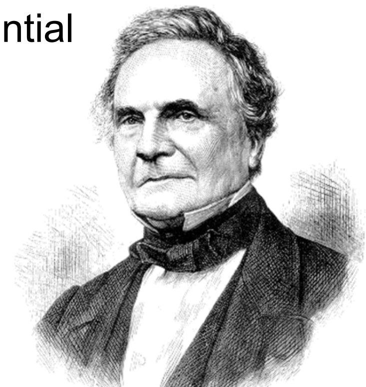
The analytical engine had an "external tape"

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

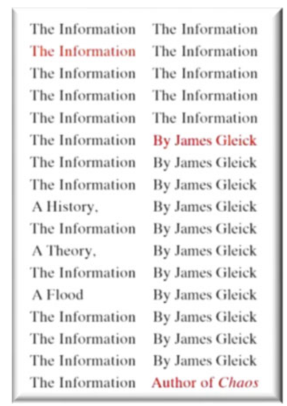
- general-purpose mechanical digital computer.
  - Separated **memory store** from a **central processing unit** (or 'mill')
  - able to select from among **alternative actions** consequent upon the outcome of its previous actions
    - Conditional branching: Choice, information
  - Mechanical cogs not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

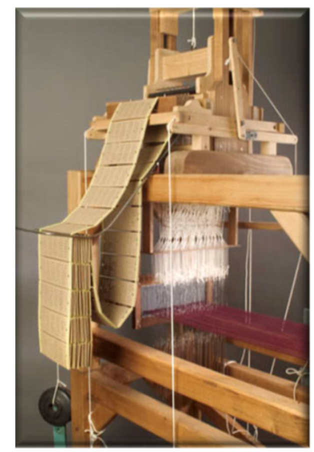


"It is only a question of cards and time, […] and there is no reason why (twenty thousand) cards should not be used if necessary, in an Analytical Engine for the purposes of the mathematician". Henry Babbage (1888)

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*.

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.