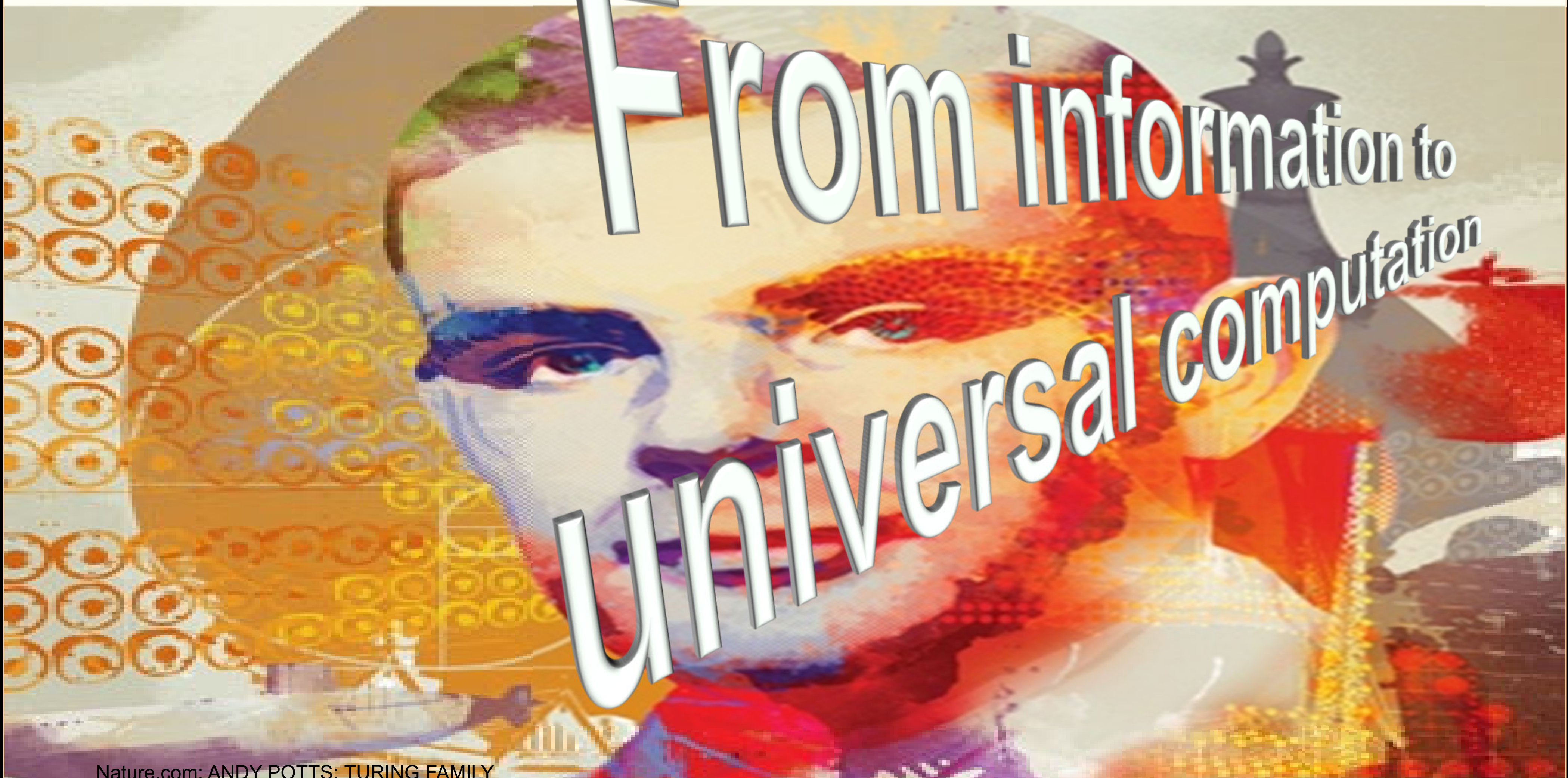
lecture 3

From information to universal computation



Nature.com; ANDY POTTS; TURING FAMILY

Complex adaptive systems and computational intelligence (casci lab)

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/358842

SSIE-501/ISE-440 - Fall 2024

luis m. rocha

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

office hours:
Tu & Th: 10:30-13:00
K1,binghamton.zoom.us/j/5124743874

bit.ly/atBIC

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evaluation

- Participation: 20%.
  - class discussion, everybody reads and discusses every paper
  - engagement in class
- Paper Presentation and Discussion: 20%
  - **SSIE501** students are assigned to papers individually or as group lead presenters and discussants
    - all students are supposed to read and participate in discussion of every paper.
  - Presenter 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 chose one of the presented papers to participate as lead discussant
    - not to present the paper, but to comment on points 2-3) above
  - Class discussion is opened to all
    - lead discussant ensures we 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
    - Enginet students post/send video or join by Zoom synchronously
- Module 1: Cybernetics and the Information Turn
- Next classes
  - Discussion Set 1 (Group 1): September 5th
    - Kline, Ronald R [2015]. *The cybernetics moment, or, why we call our age the information age*. Johns Hopkins University Press. Chapters 1-2.
      - Optional: Heims, S.G. [1991]. *The Cybernetics Group*. MIT Press. Chapters: 1,2, 11, and 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.
  - Discussion Set 2 (Group 2)
    - 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.
  - **Discussion by all**

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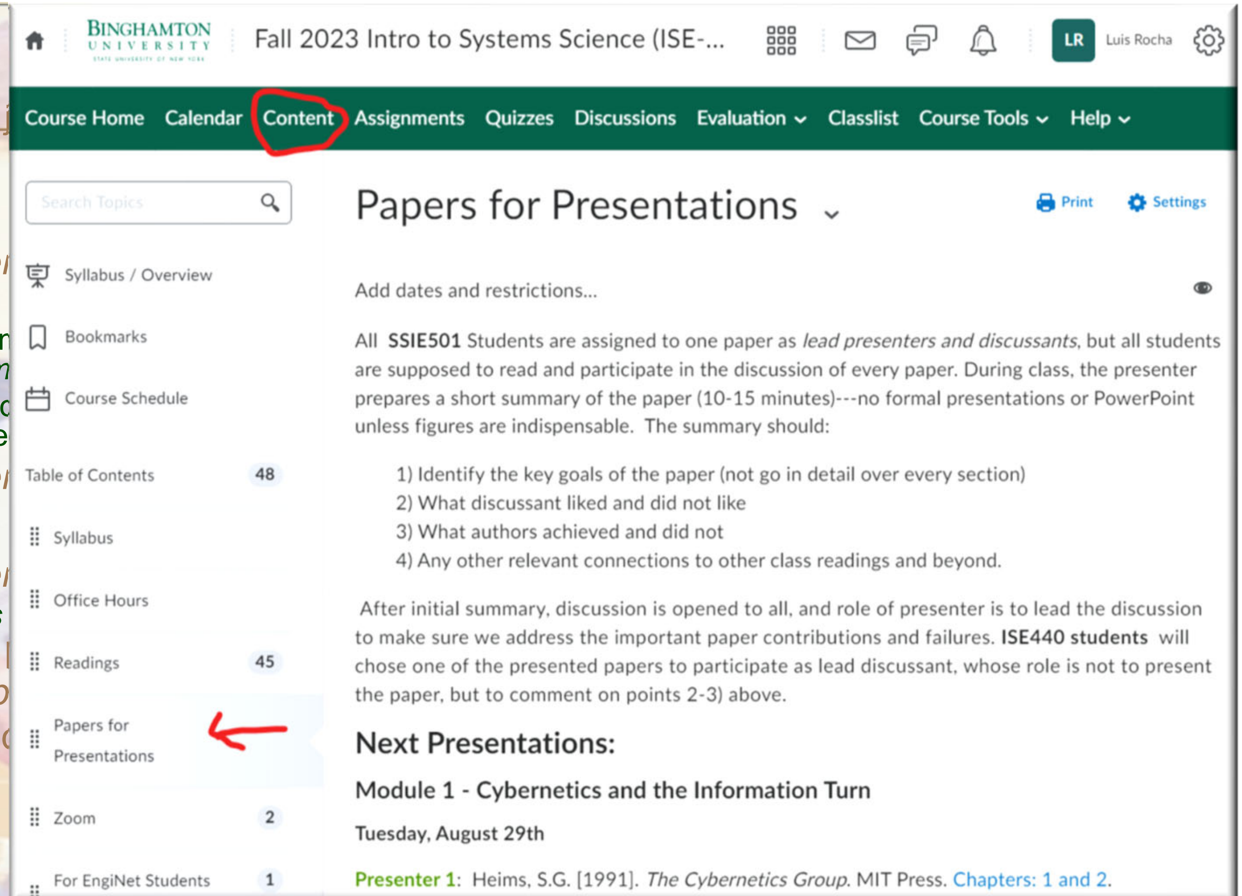
more upcoming readings (check brightspace)

- Paper Presentation: 20%
  - Present (501) and lead (501&440)
    - Enginet students post/send video or j
- Module 2: Systems Science
  - Discussion Set 3:
    - Klir, G.J. [2001]. *Facets of syste*
      - Optional:
      - Rosen, R. [1986]. "Some commen Klir, G.J. [2001]. *Facets of system*
      - Wigner, E.P. [1960], "The unreaso in mathematical sciences delivere
    - Klir, G.J. [2001]. *Facets of syste*
  - Discussion Set 4:
    - Klir, G.J. [2001]. *Facets of syste*
      - Optional: Klir, G.J. [2001]. *Facets*
    - Schuster, P. (2016). The end of l of computational facilities. *Comp*
    - Von Foerster, H., P. M. Mora and Science **132**(3436):1291-5.
- Future Modules
  - See brightspace




How did we get here?
MEDIA
NETWORK SEARCH
WORLD
BUSINESS

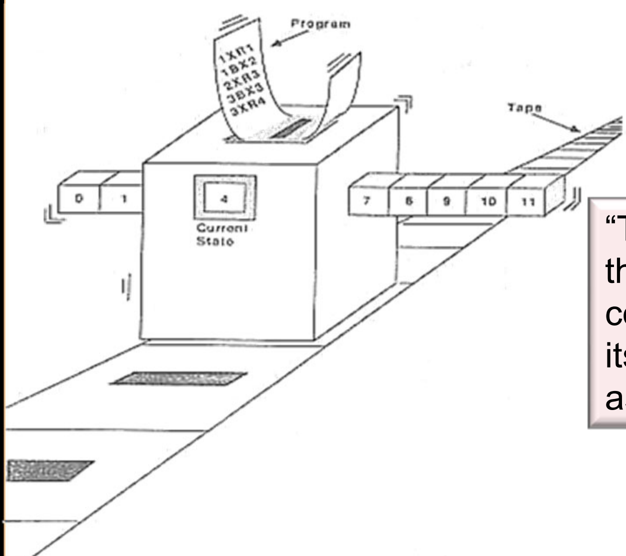
key contributions (most relevant to biocomplexity)

- "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.

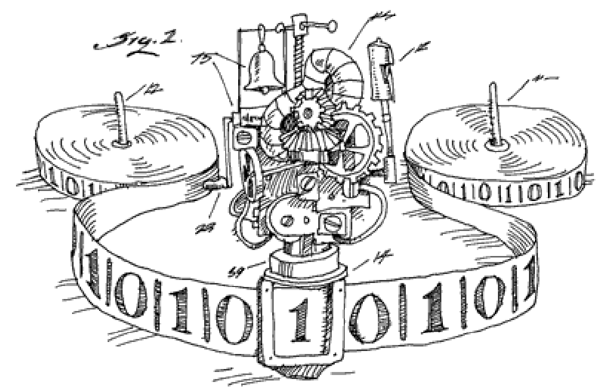
A fundamental principle of computation

- “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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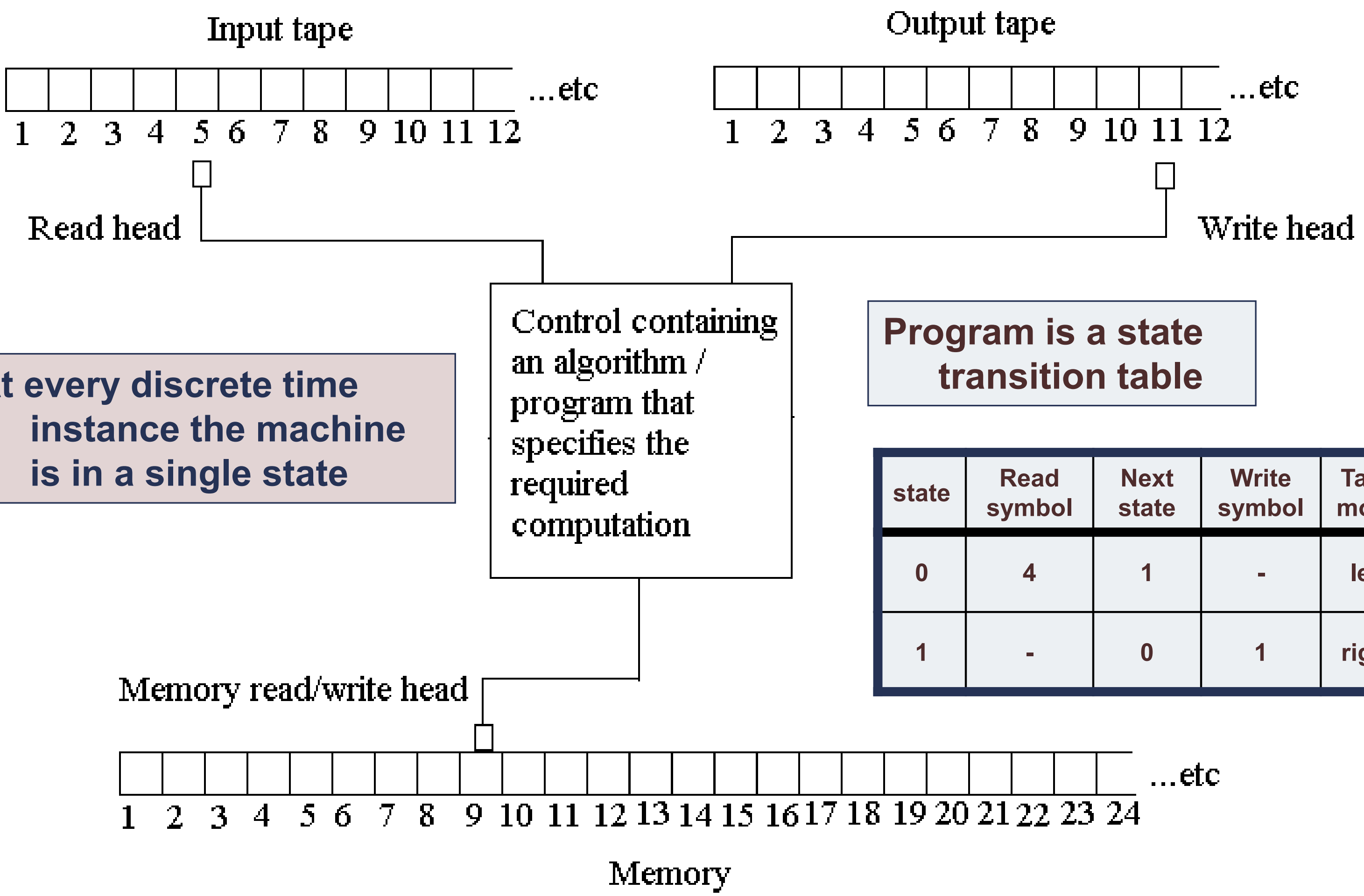
A Turing Machine



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

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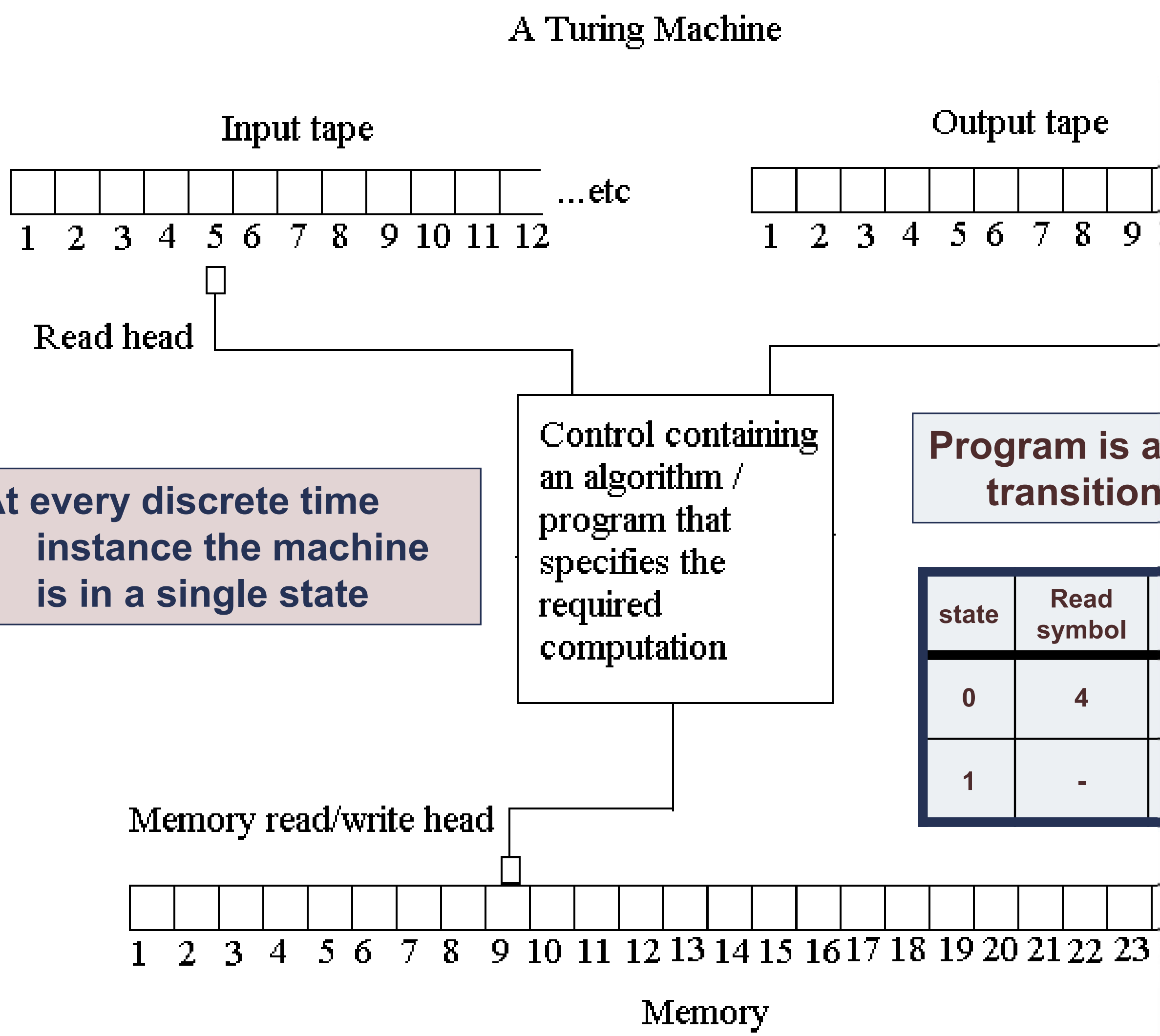

At every discrete time instance the machine is in a single state

Program is a transition

state	Read symbol
0	4
1	-

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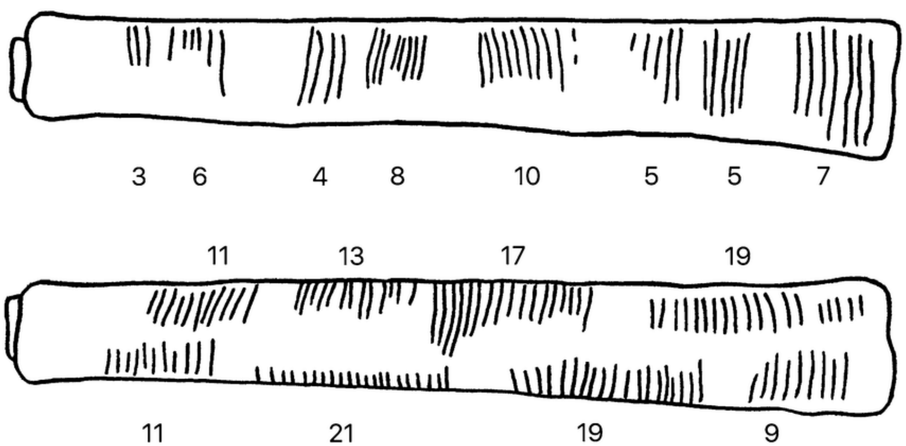
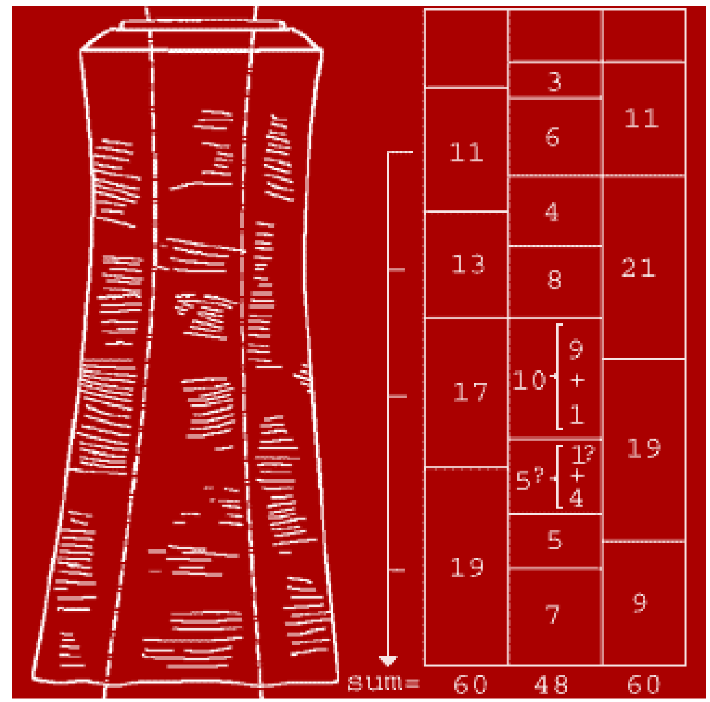
where do numbers come from?

- 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

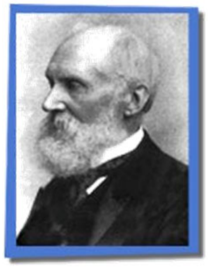




abstracting symbol mappings

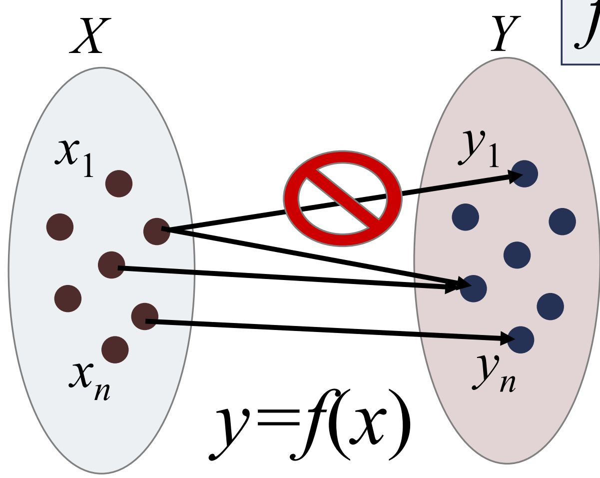
- Counting
  - A measurement process from a physical system to a symbol
    - A mapping between discrete objects and symbols
    - First numbers were not completely abstract
      - Specific attributes of concrete objects
- Computation
  - Abstract concept of one-to-one pairing of symbols
  - Mathematical 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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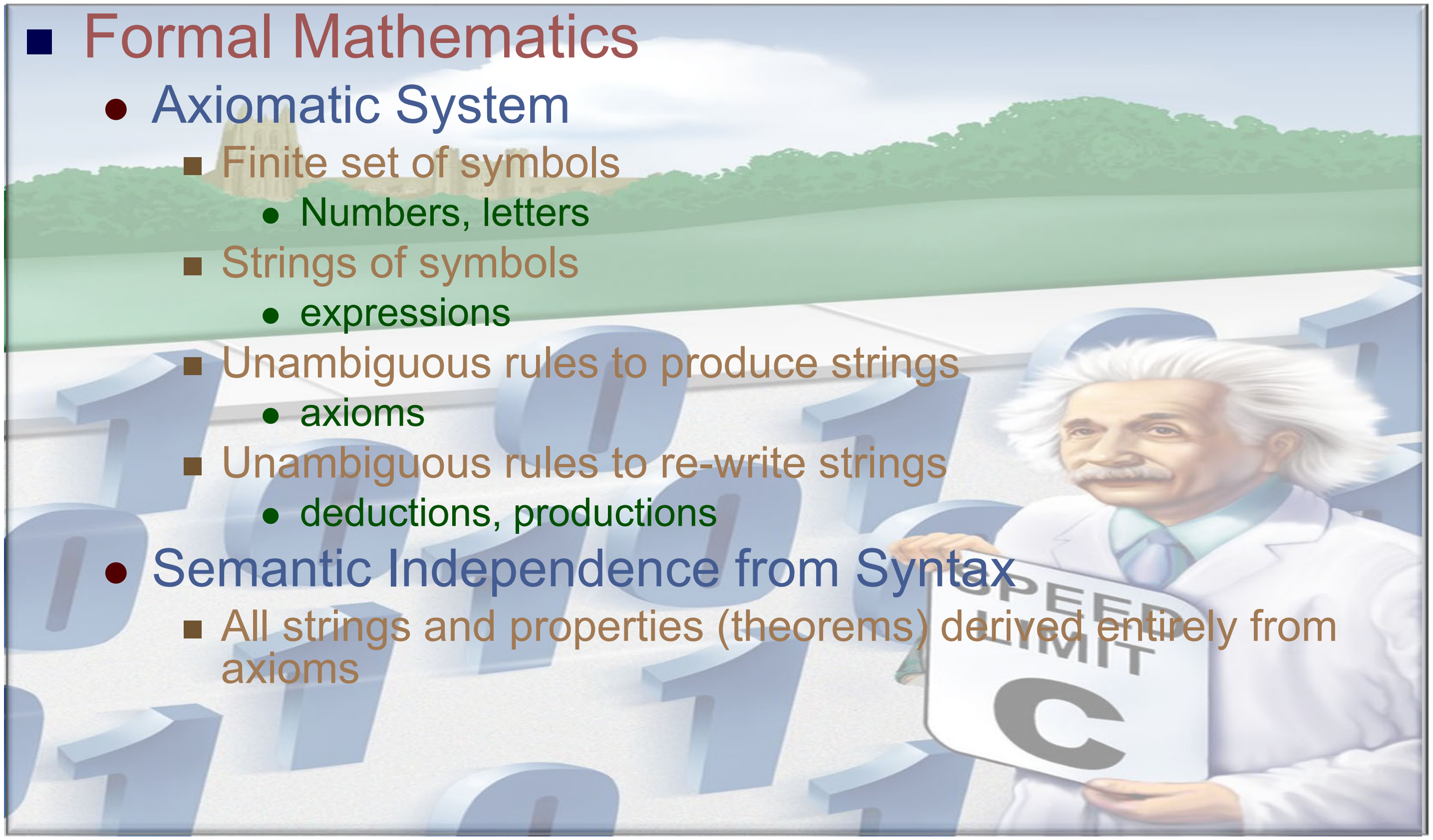
abstracting symbol mappings

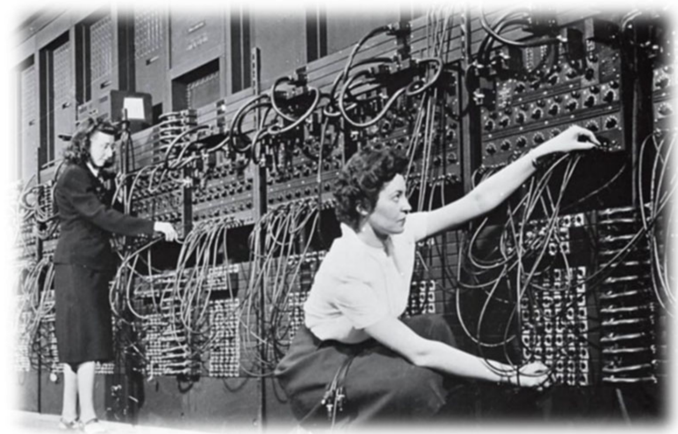


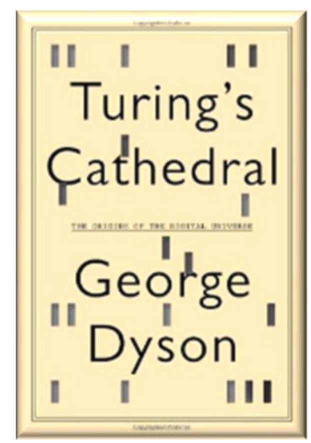
- **Formal Mathematics**
  - Axiomatic System
    - Finite set of symbols
      - Numbers, letters
    - Strings of symbols
      - expressions
    - Unambiguous rules to produce strings
      - axioms
    - Unambiguous rules to re-write strings
      - deductions, productions
  - Semantic Independence 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

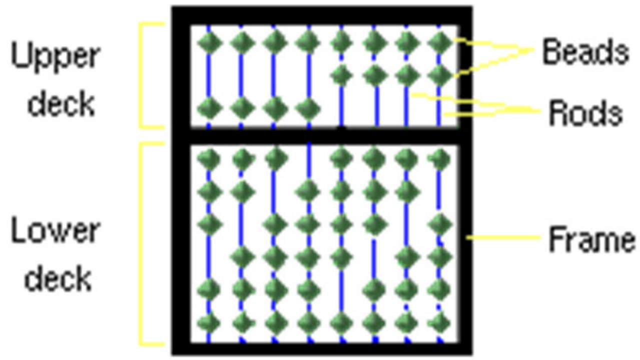
- Process of rewriting strings in a formal system according to a program of rules
  - Operations and states are syntactic
  - Symbols follow syntactical rules
  - Rate of computation is irrelevant
    - Program determines result, not speed of machine
  - Physical implementation is irrelevant for result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

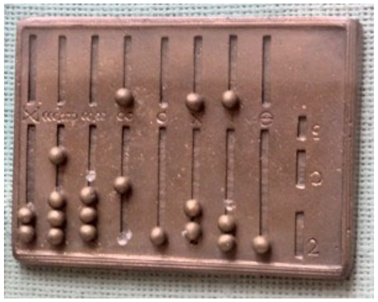




"[…] essential elements in the machine are of a binary […] nature. Those whose state is determined by their history and are time-stable are memory elements. Elements of which the state is determined essentially by the existing amplitude of a voltage or signal are called 'gates'". Bigelow et al, 1947

- 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.





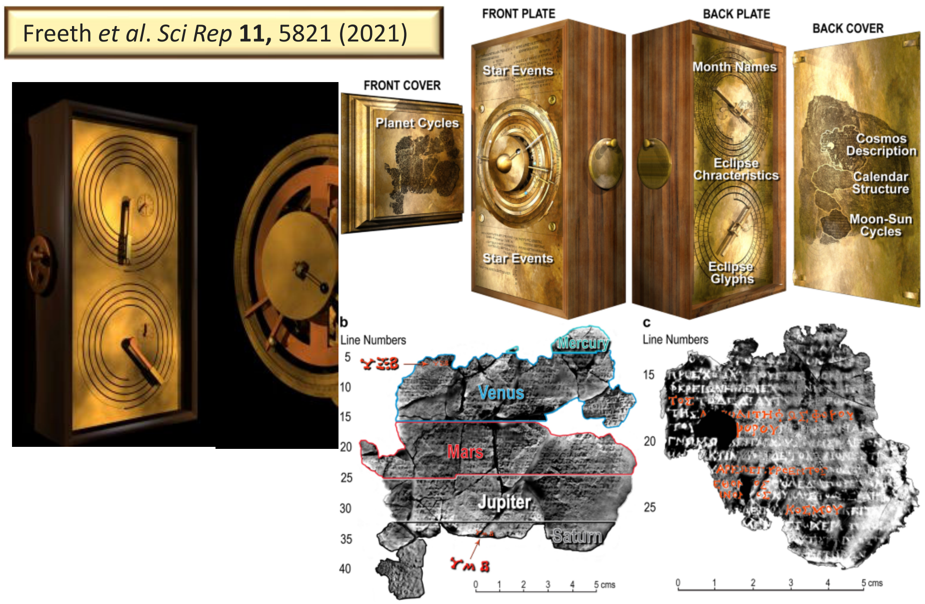
Reconstruction of a Roman abacus in the *Cabinet des Médailles, Bibliothèque nationale*, Paris.

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

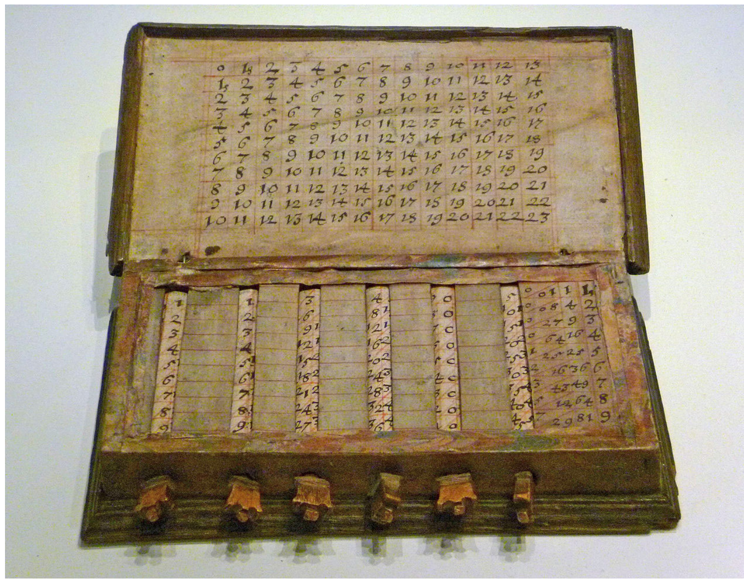
Freeth *et al*. *Sci Rep* **11,** 5821 (2021)

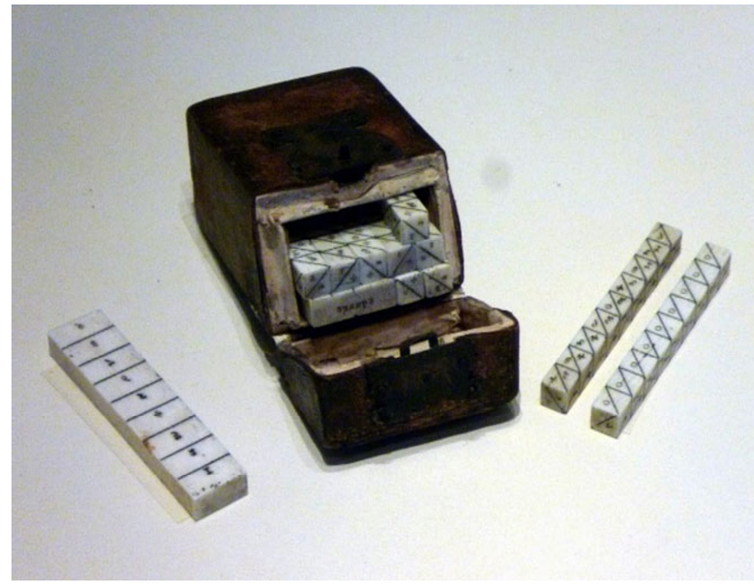


are people (and tables) too!

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

MIRIFICI
Logarithmorum
Canonis descriptio,
Ejusque usus, in utraque
Trigonometria; ut etiam in
omni Logistica Mathematica,
Amplissimi, Facillimi, &
expeditissimi explicatio.
Authore ac Inventore,
IOANNE NEPERO,
Barone Merchistonii,
&c. Scoto.
EDINBVRGI,
Ex officina ANDREÆ HART
Bibliopolæ, CIↃ. DC. XIV.





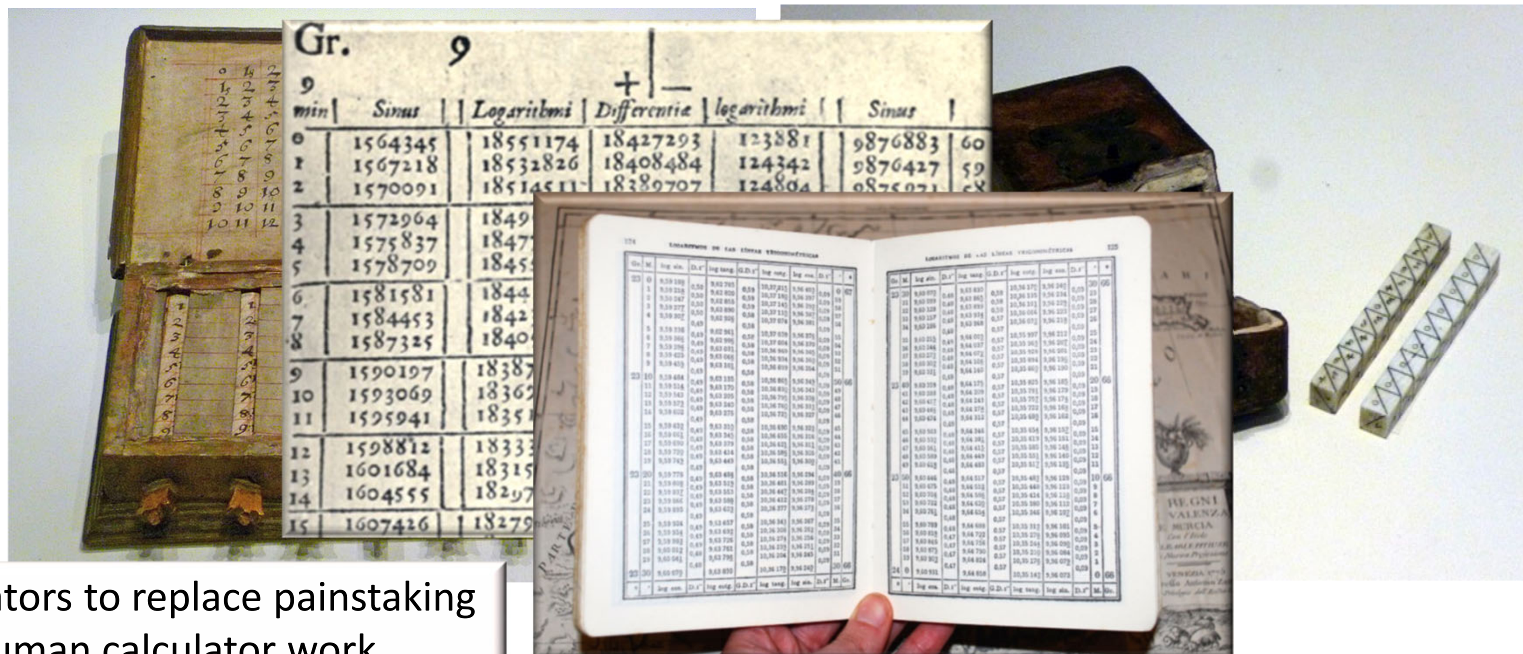
Briggs (1561-1630): decimal algorithm, logs of 30,000 numbers to 14 decimal places and logs/tans of 1/100 of every degree, 14 decimal places

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

computers

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

readings

- Class Book
  - Klir, G.J. [2001]. *Facets of systems science*. Springer.
- Papers and other materials
  - Discussion Set 1 (Group 1) – September 3rd or 5th
    - Kline, Ronald R [2015]. *The cybernetics moment, or, why we call our age the information age*. Johns Hopkins University Press. Chapters 1-2.
      - Heims, S.G. [1991]. *The Cybernetics Group*. MIT Press. Chapters: 1,2, 11, 12.
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