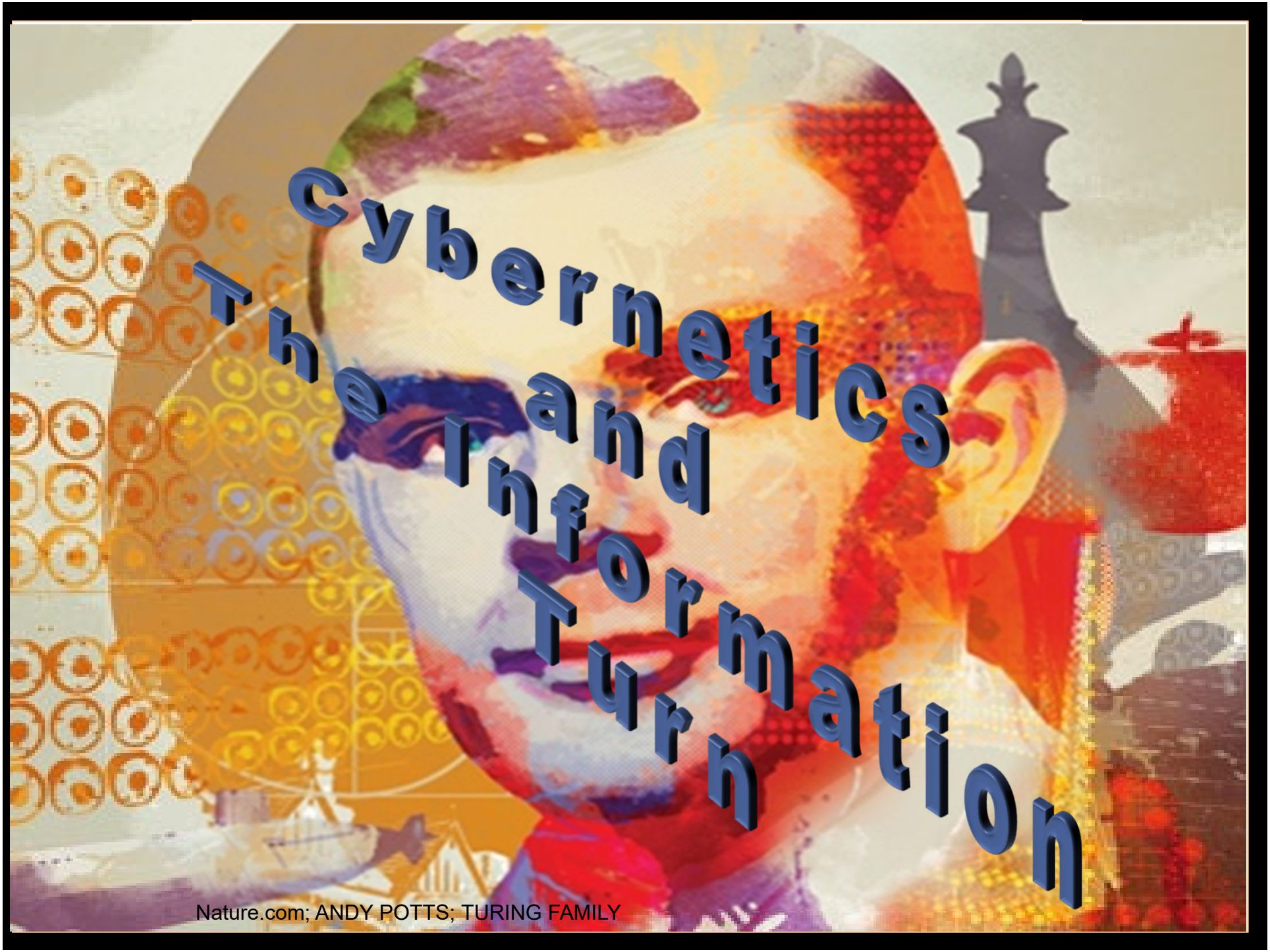
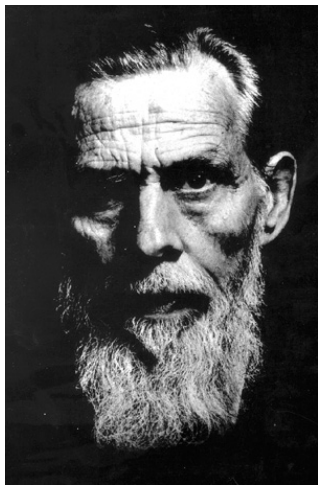


Nature.com; ANDY POTTS; TURING FAMILY

McCulloch & Pitts

Memory can be maintained in circular networks of binary switches

- McCulloch, W. and W. Pitts [1943], "A Logical Calculus of Ideas Immanent in Nervous Activity". *Bulletin of Mathematical Biophysics* **5**:115-133.
  - A Turing machine program could be implemented in a finite network of binary neuron/switches
    - Neurons as basic computing unit of the brain
    - Circularity is essential for memory (closed loops to sustain memory)
  - Brain (mental?) function as computing
- Others at Macy Meeting emphasized other aspects of brain activity
  - Chemical concentrations and field effects (not digital)
    - Ralph Gerard and Fredrik Bremmer



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cybernetics

post-war science

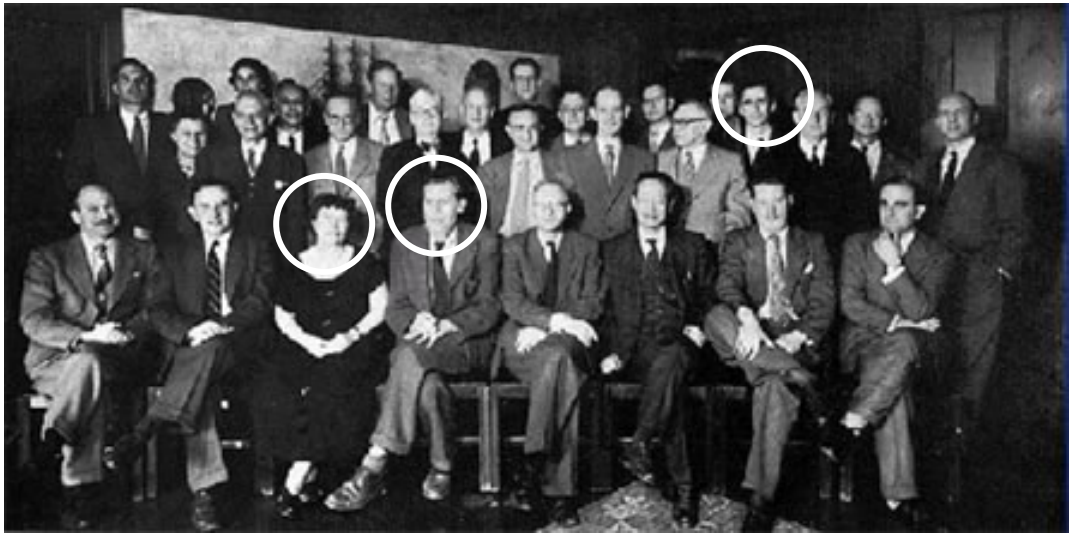
- Synthetic approach
  - Engineering-inspired
  - Supremacy of mechanism
- Postwar culture of problem solving
  - Interdisciplinary teams
  - Cross-disciplinary methodology
- All can be axiomatized and computed
  - Mculloch&Pitts' work was major influence
    - "A logical calculus of the ideas immanent in nervous activity". *Bulletin of Mathematical Biophysics* **5**:115-133 (1943).
    - A **Turing machine** (any function) could be implemented with a **network** of **simple binary switches** (if circularity/feedback is present)

Macy Conferences: 1946-53

Warren S. McCulloch

Margaret Mead

Claude Shannon



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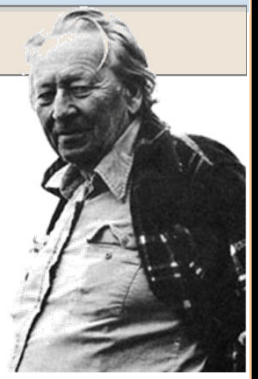
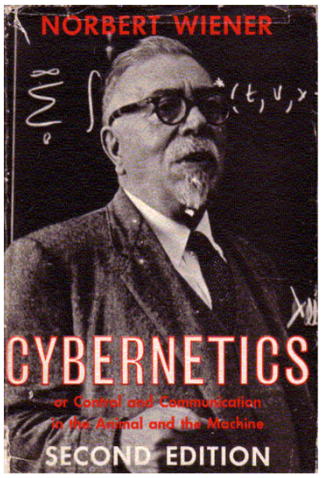
cybernetics

universal computers and general-purpose informatics

- the Josiah Macy Jr. Foundation Meetings
  - post-war science
    - 1946-1953
- Interdisciplinary
  - Since a large class of ordinary phenomena exhibit circular causality, and mathematics is accessible, let's look at them with a war-time team culture
- Participants
  - **John Von Neumann**, Leonard Savage, **Norbert Wiener**, **Arturo Rosenblueth**, Walter Pitts, **Margaret Mead**, Heinz von Foerster, **Warren McCulloch**, **Gregory Bateson**, Claude Shannon, Ross Ashby, etc.
- Key concepts
  - **universal computation** (Turing, Von Neumann), information (Shannon, Wiener), **networks** (mcCulloch), homeostasis, **feedback**, complexity, self-organization
  - mind, society, life as general mechanisms





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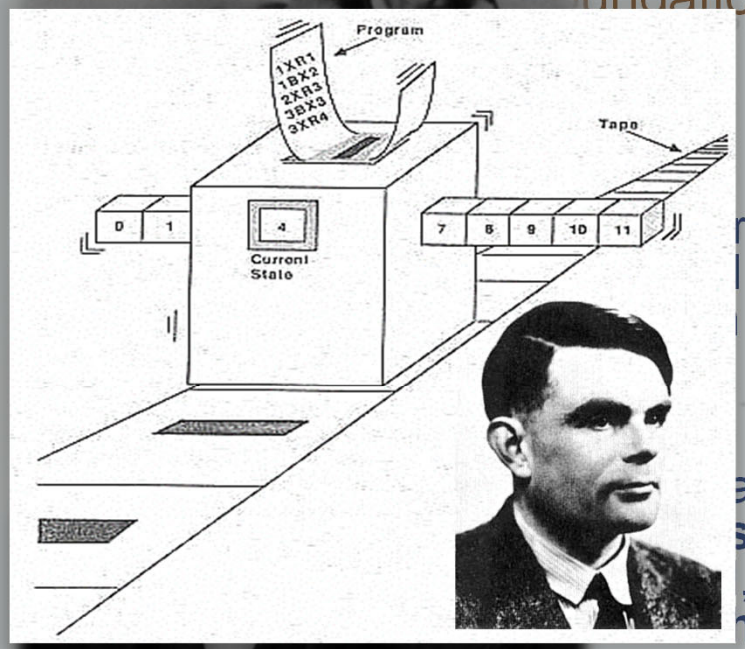

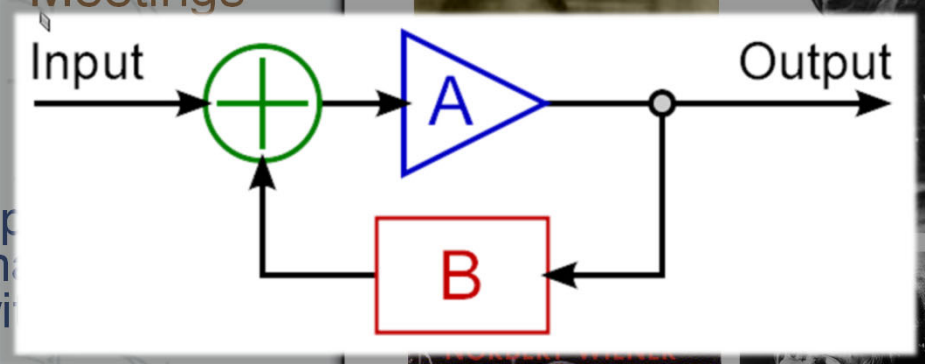

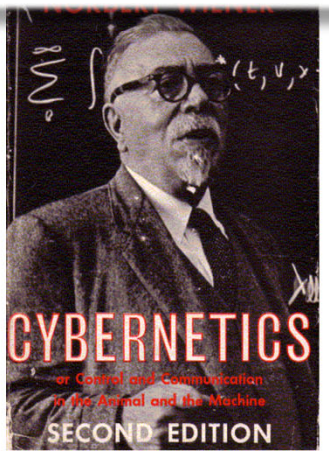

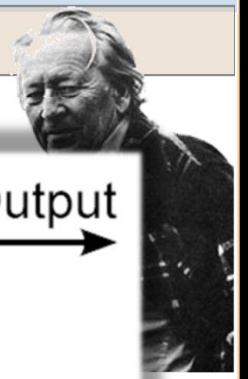

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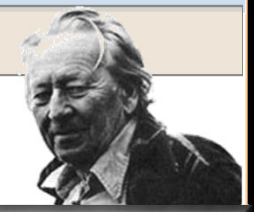
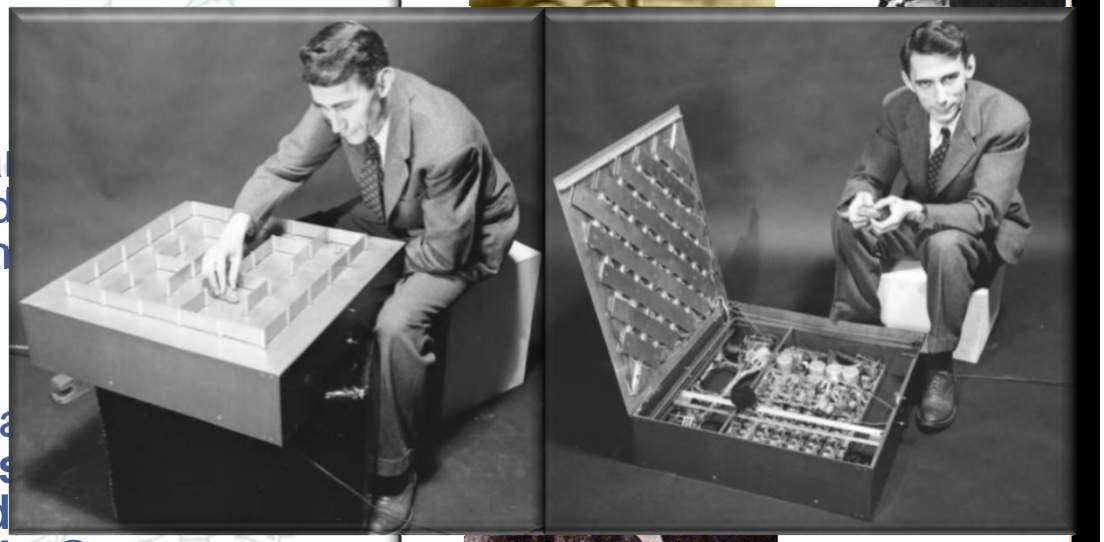
universal computers and general-purpose informatics

- the Josiah Macy, Jr. Foundation Meetings





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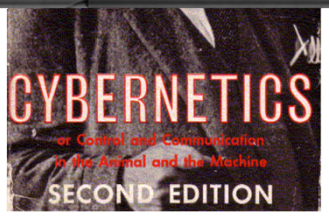

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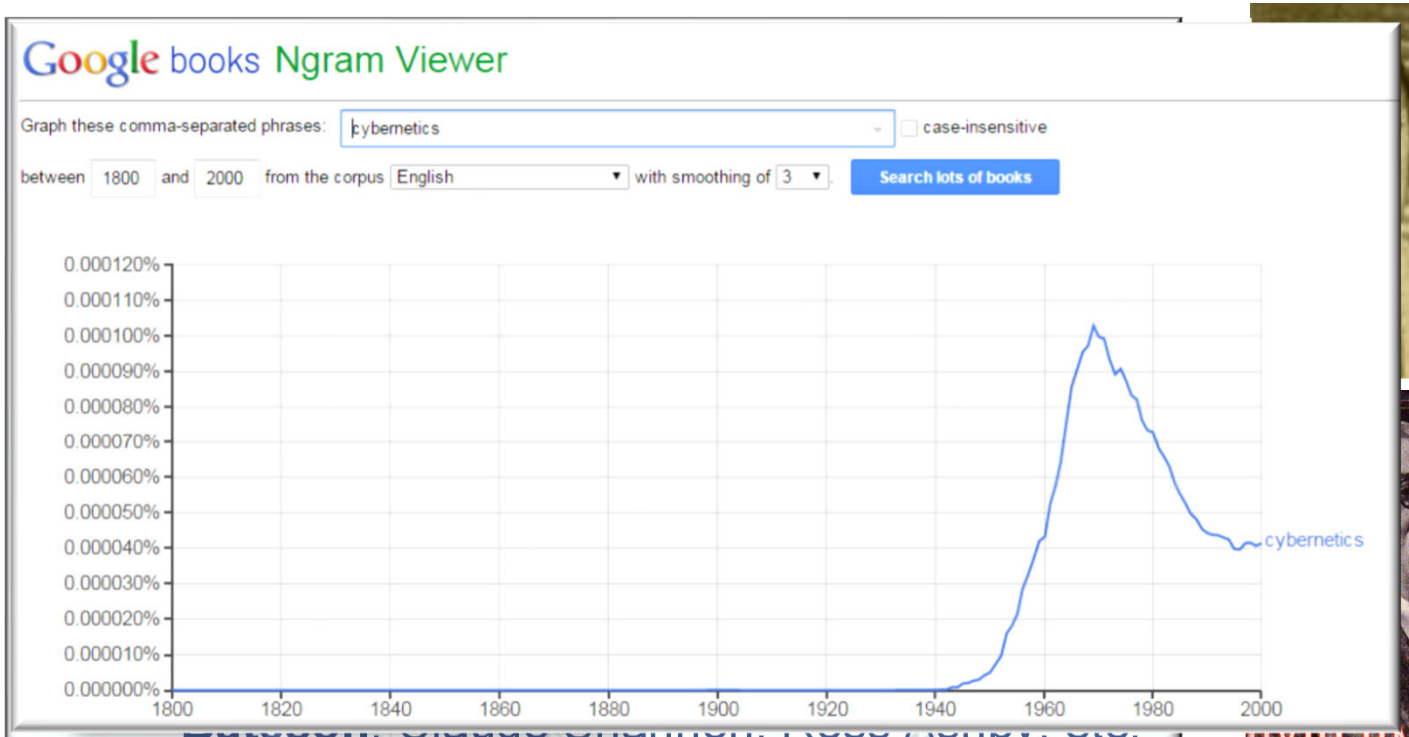

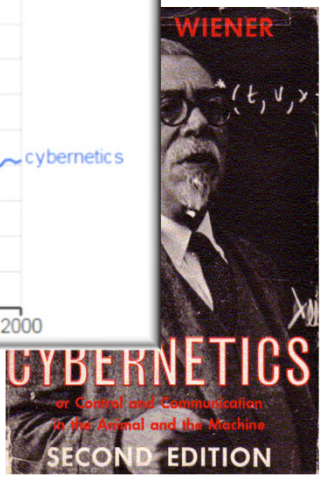

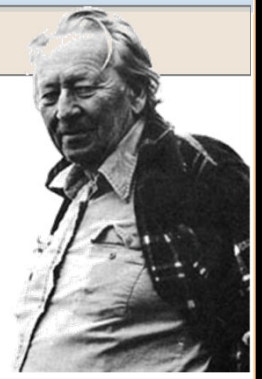

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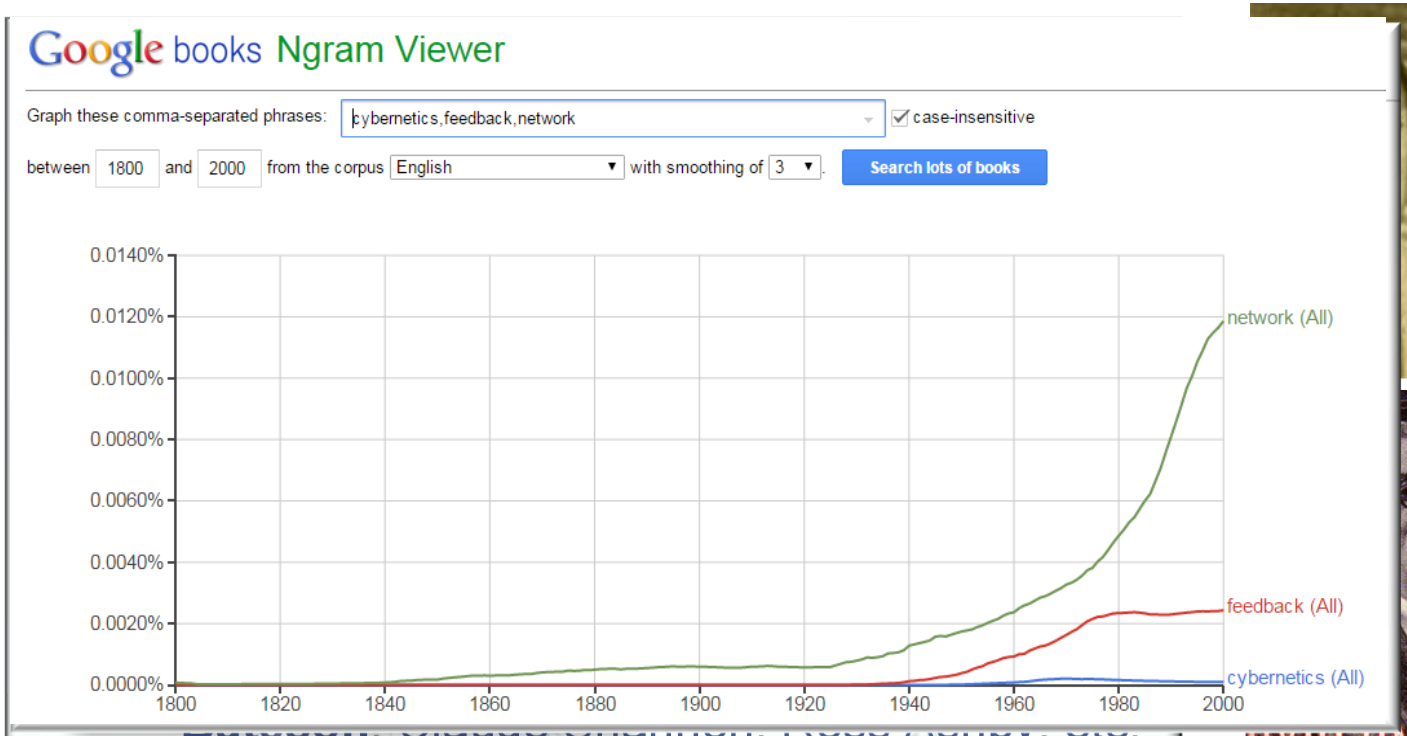

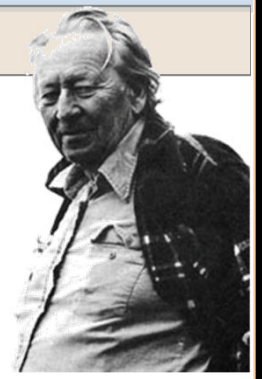

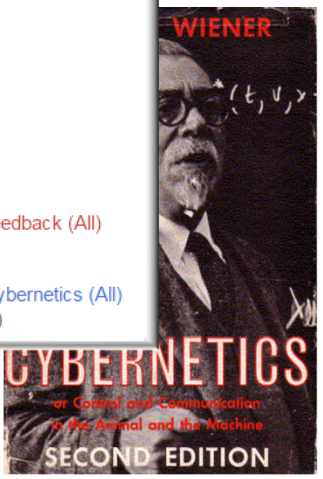

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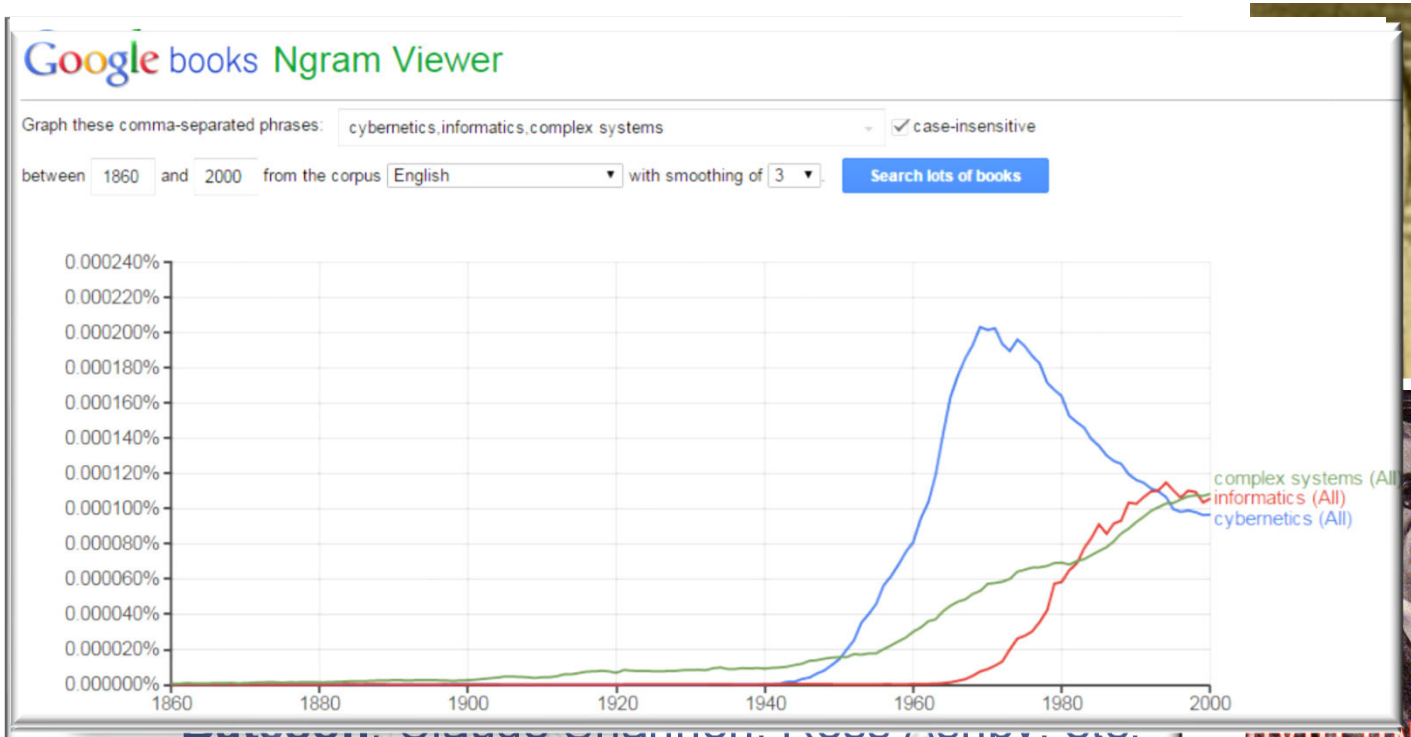

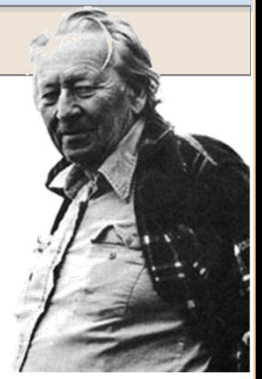

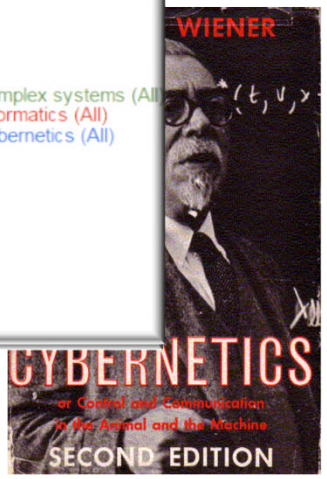

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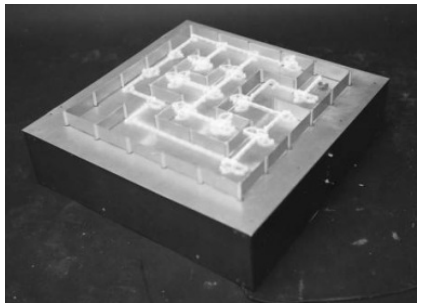
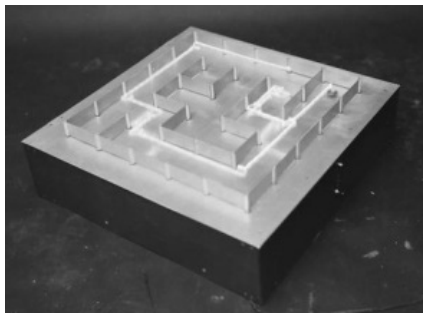
Shannon's mouse

controlling information to achieve life-like behavior

- trial and error algorithm
  - information as reduction of uncertainty in the presence of alternatives (combinatorics)
- lifelike behavior
  - trial and error to **learn** path from many alternatives
  - adapts to new situations
- how is learning achieved?
  - Correct choices, **information** gained from reduced uncertainty, must be **stored in memory**
- **memory of information** as a design principle of intelligence in uncertain environments
  - 75 bit memory
  - stored in (telephone) switching relays
    - Brain as (switching) machine





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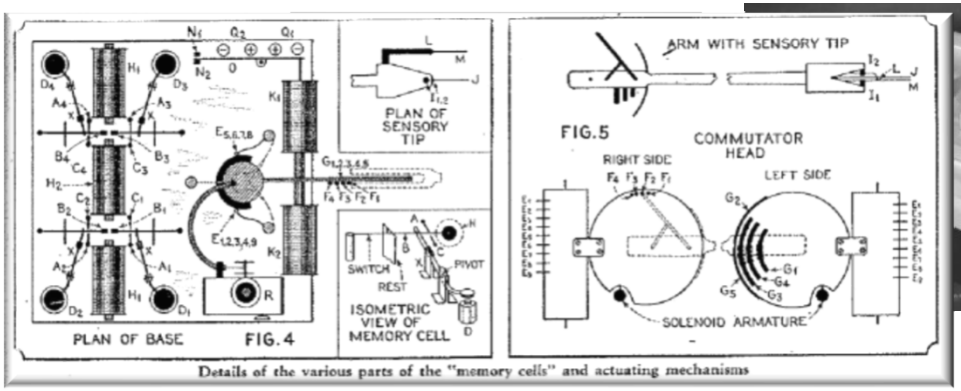
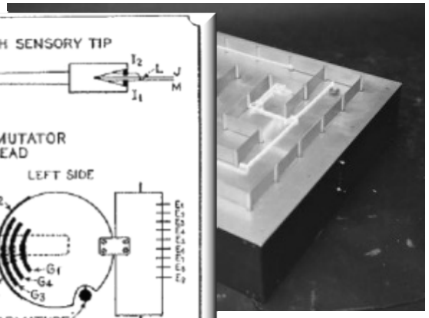
controlling information to achieve life-like behavior



Details of the various parts of the "memory cells" and actuating mechanisms



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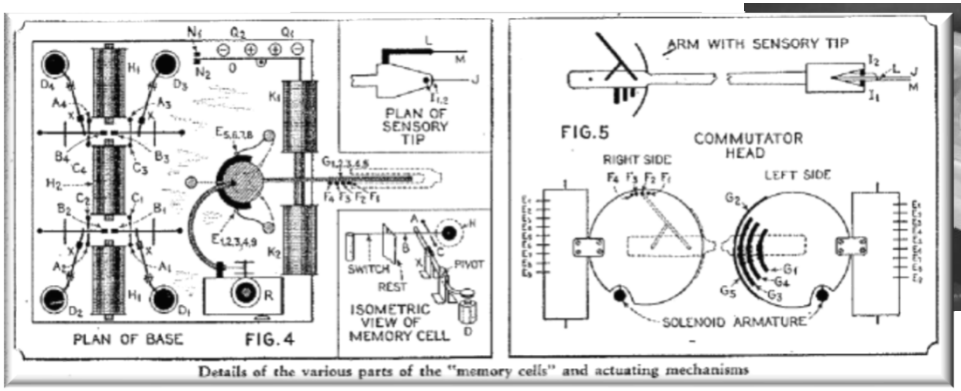

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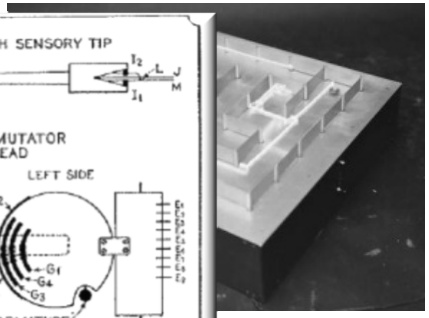

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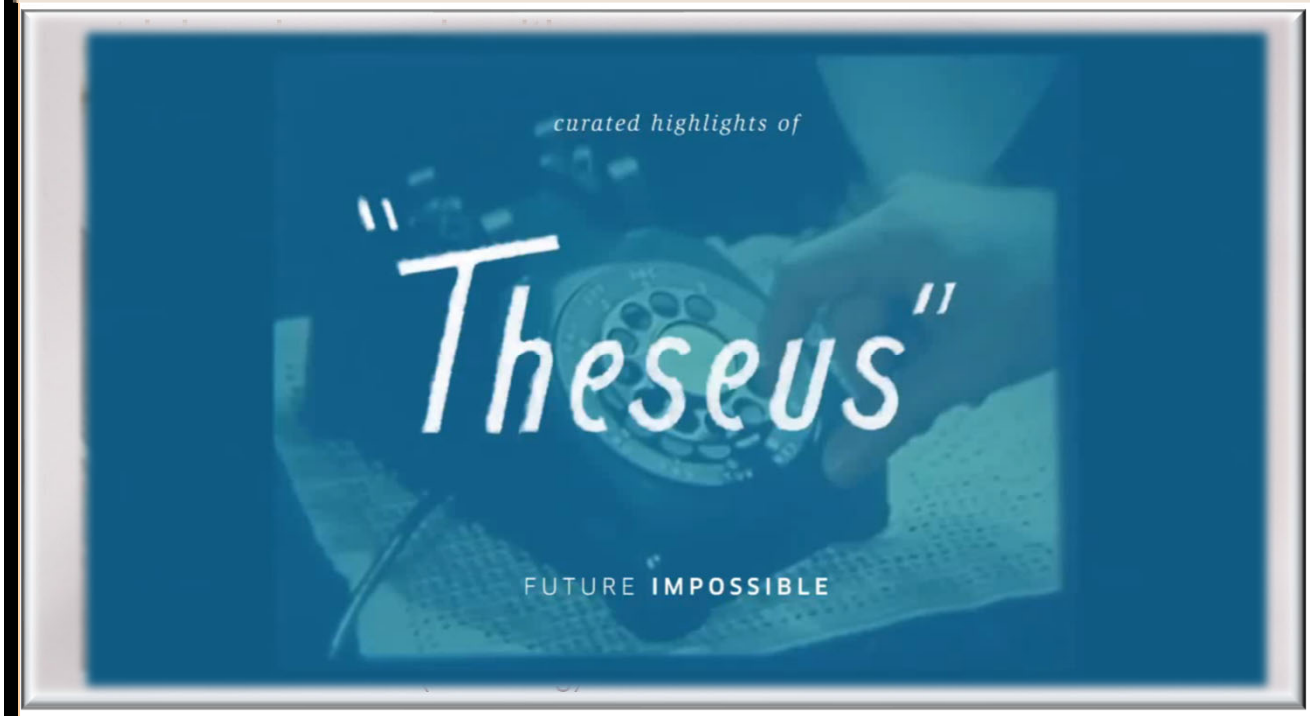

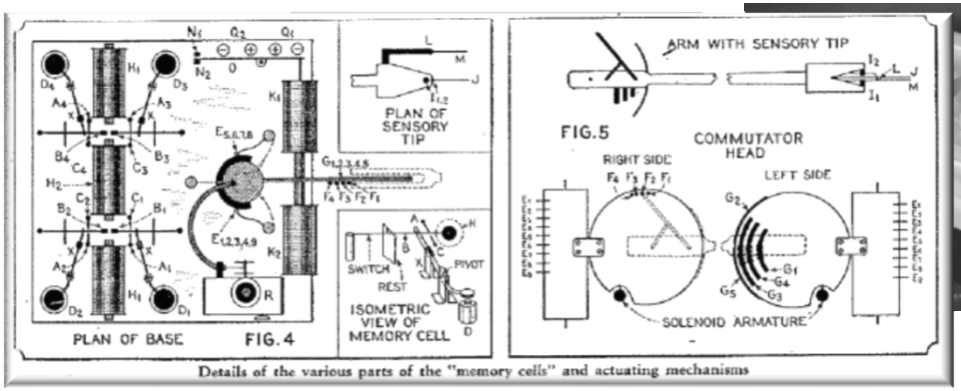

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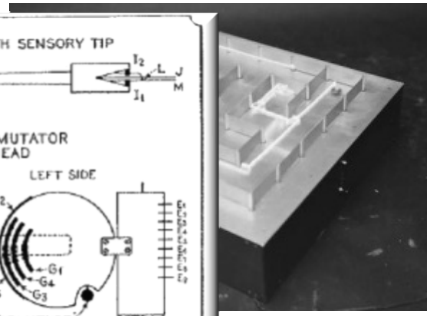

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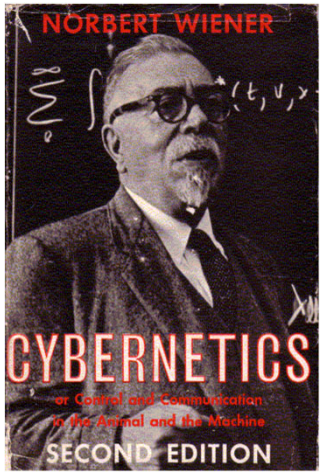
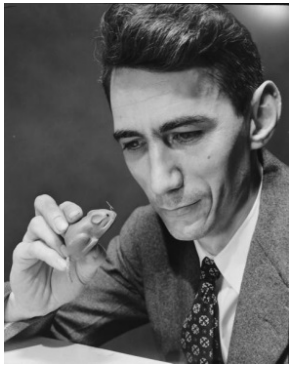
other key concepts

at the Macy meetings

- Norbert Wiener and Arturo Rosenblueth
  - Goal-directed behavior and negative feedback (control)
  - Homeostasis and circular causality
    - In machines and biology
- Automata Theory (Von Neumann)
- Communication and Information
  - The fundamental idea is the message, even though the message may not be sent by man and the fundamental element of the message is the decision" (Norbert Wiener)
  - *Shannon's Information and Wiener's Communication Theory*
  - Natural semiotics (McCulloch and others later get into Peircean Semiotics)
- "functional equivalence" of systems (general systems)
  - Bio-inspired mathematics and engineering and computing/mechanism-inspired biology and social science





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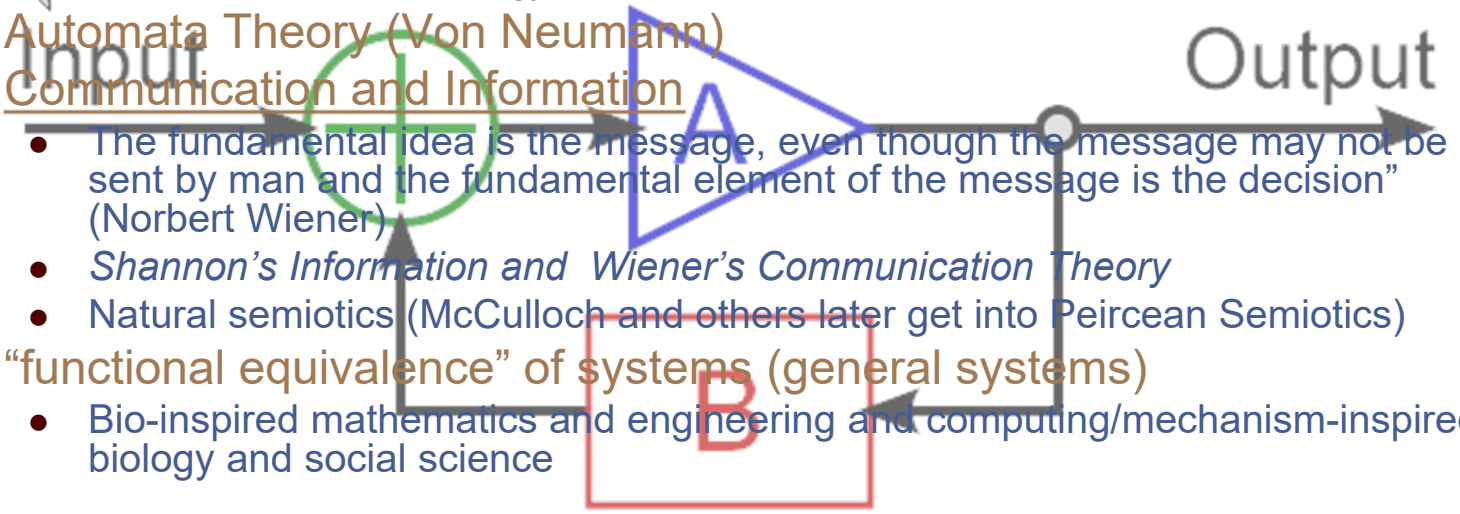

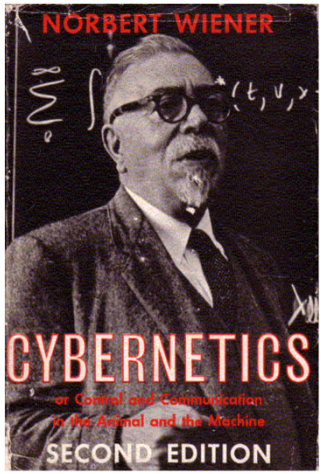

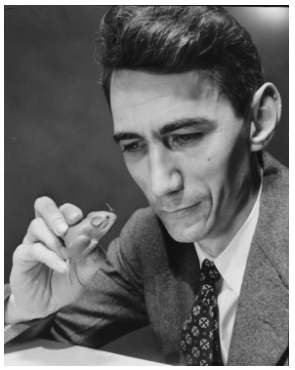

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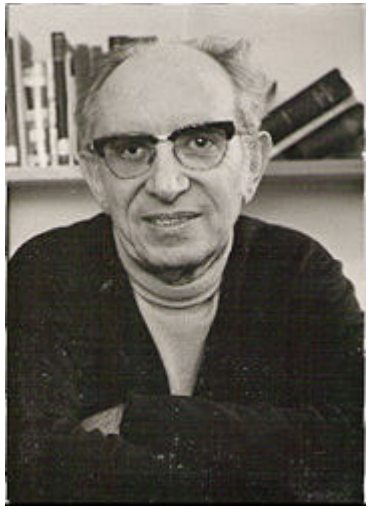
other key concepts

at the Macy meetings

- Gregory Bateson and Margaret Mead
  - Homeostasis and circular causality in society
    - Transvestite ceremony to diffuse aggressive action in latmul culture
  - Learning and evolution
    - Can a computer learn to learn?
  - A new organizing principle for the social sciences (control and communication)
    - As much as evolution was for Biology
- Lawrence Frank
  - The new interdisciplinary concepts needed a new kind of language
    - Higher generality than what is used in single topic disciplines
    - A call for a science of systems
- Yehoshua Bar-Hillel
  - Optimism of a new (cybernetics and information) age
    - "A new synthesis […] was destined to open new vistas on everything human to help solve many of the disturbing open problems concerning man and humanity".


Gregory Bateson & Margaret Mead



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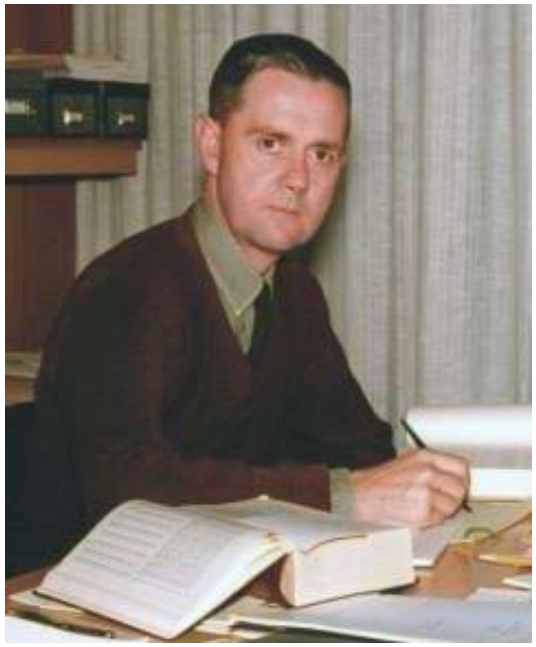
British Cybernetics

Turing as cybernetician

- The Ratio Club (starting in1949)
  - British cybernetics meetings
    - William Ross Ashby, W. Grey Walter, Alan Turing. etc
  - "computation or the faculty of mind which calculates, plans and reasons"
  - Also following Wiener's use of "*Machina ratiocinatrix*" in Cybernetics (1948), following Leibniz' "*calculus ratiocinator*"



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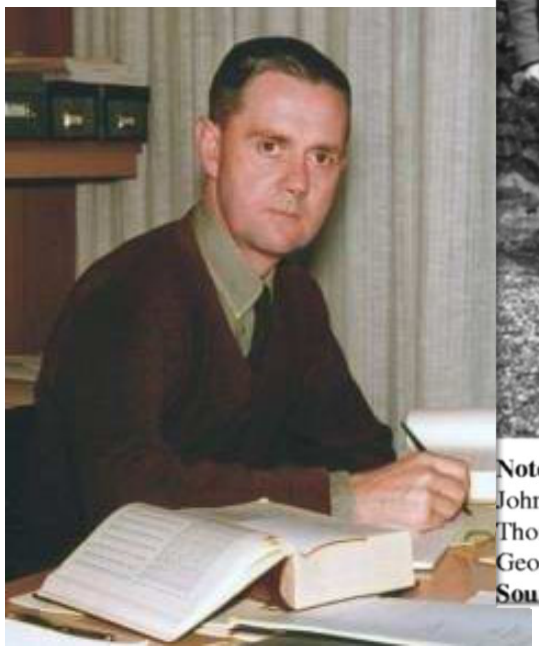

Notes: Back row (from the left): Harold Shipton, John Bates, William Hick, John Pringle, Donald Sholl, John Westcott, and Donald Mackay; middle row: Giles Brindley (guest), Turner McLardy, Ross Ashby, Thomas Gold, and Albert Uttley; front row: Alan Turing, Gurney Sutton (guest), William Rushton, George Dawson, and Horace Barlow
Source: Image courtesy of the Wellcome Library for the History and Understanding of Medicine, London

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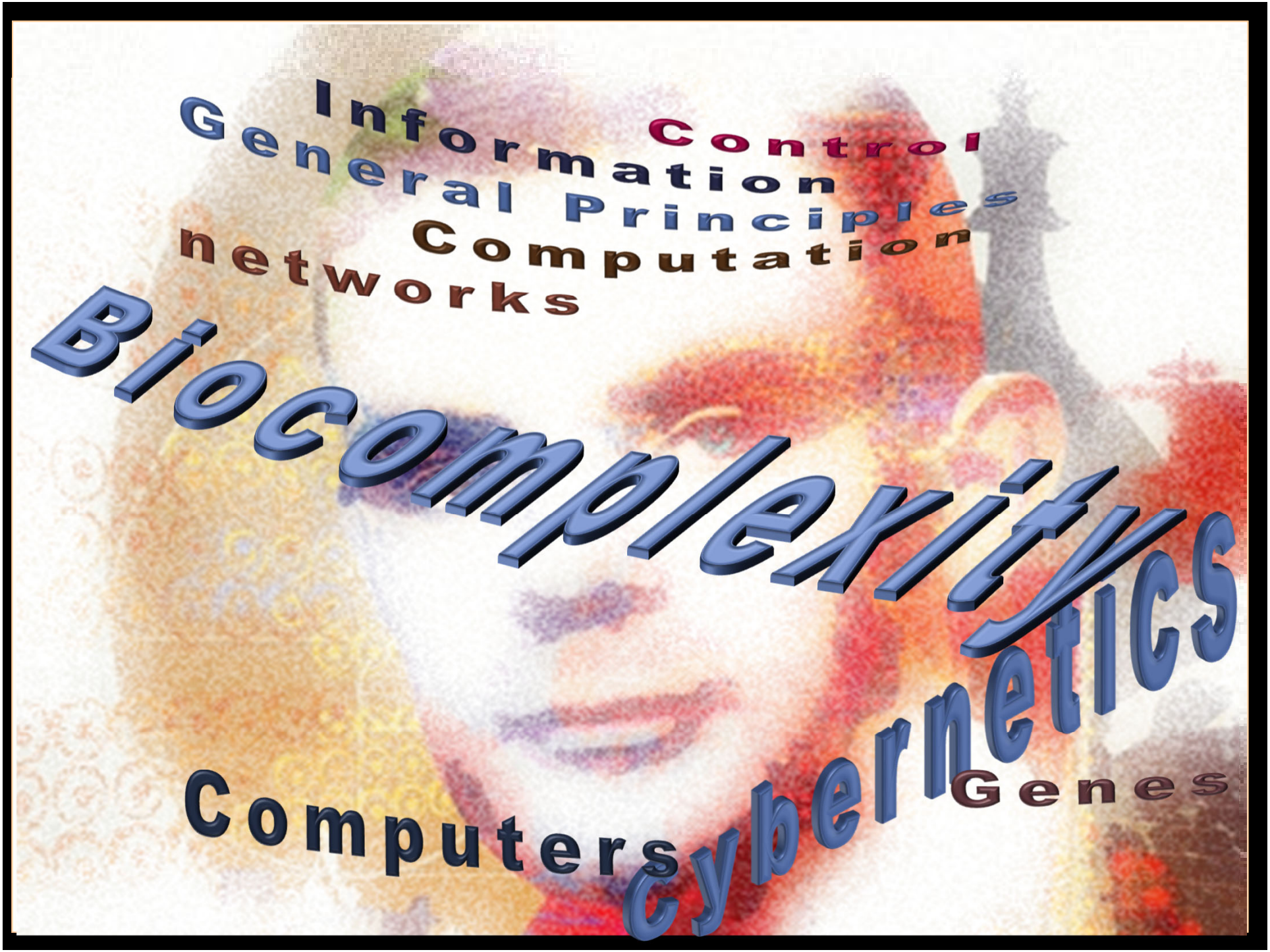
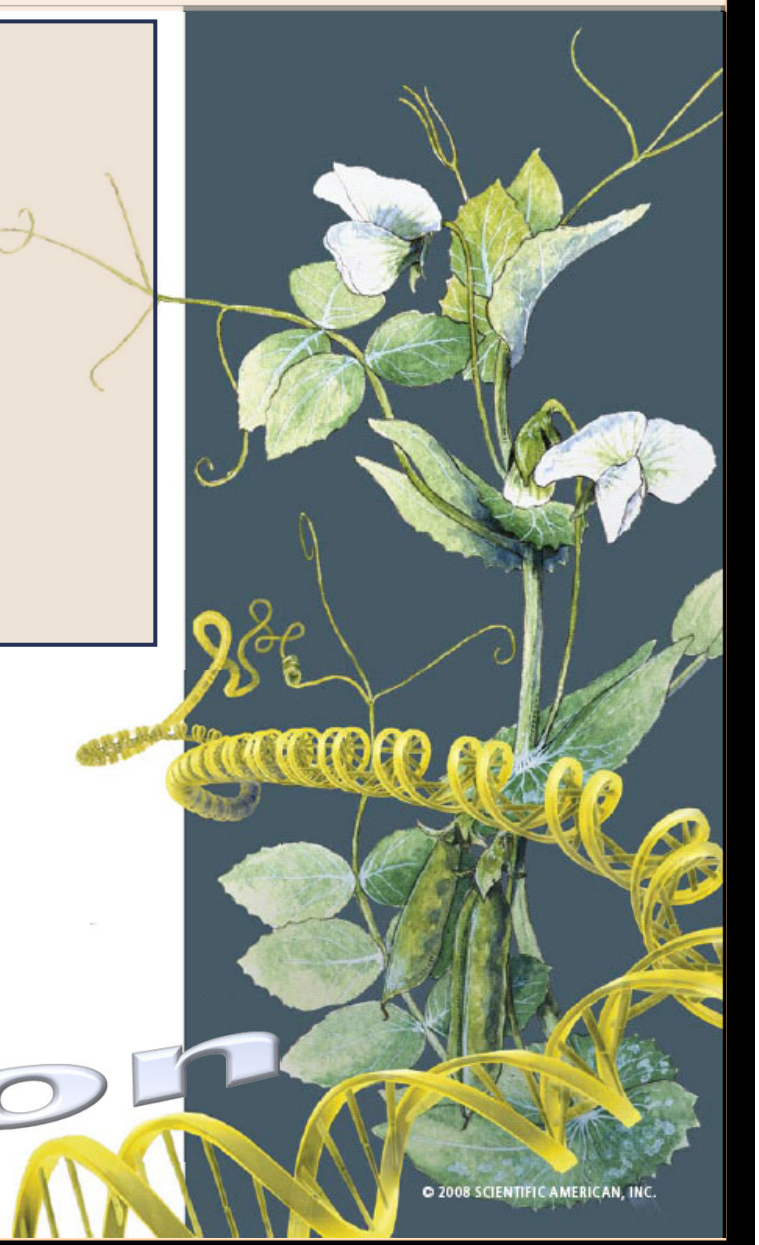

Information
Control
General Principles
Computation
networks
Biocomplexity
Cybernetics
Computers
Genes

differences and explanations

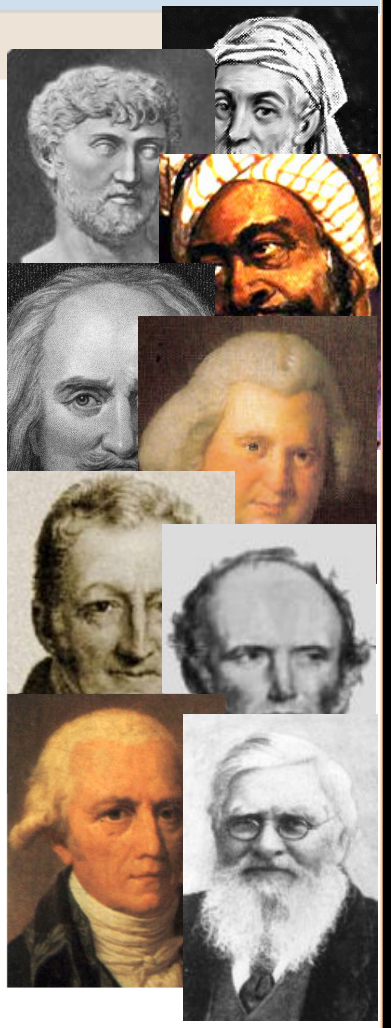
- Evolution
  - adaptation, learning, innovation, social evolution
- Mechanism
  - Reproduction, transmission, variation, selection
- Design causes
  - Natural selection
- explanation?
  - Contingent, historical, context/specific
  - Does not seem lawful

Natural Selection



Path to Darwin

- Evolution by natural selection
  - Organisms vary from one another
  - New variation appears from time to time
  - Variation is passed from parent to offspring
  - “struggle for existence” (limited resources)
- Recognized before Darwin
  - Empedocles (490–430 BC)
    - why animals adapt to environment
  - Lucretius (99 - 55 BC)
    - Random evolution, free will
  - Al-Jahiz (781 – 869 AD)
    - on the struggle for existence
  - Thomas Hobbes (XVII)
  - Erasmus Darwin (XVIII)
  - Thomas Malthus (XVIII)
    - Populations grow exponentially, resources lineraly
  - Charles Lyell (XIX)
    - Gradual change in geological landscape
  - Jean-Baptiste Lamarck (XIX)
    - Mechanism: mutation and (acquired) inheritance
  - Alfred Russel Wallace
    - Reached same conclusion as Darwin (with less evidence)
  - Charles Darwin
    - Evolution, **inevitable**



“I happened to read for amusement Malthus on population, and being well prepared to appreciate the struggle for existence…it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of new species.” [Charles Darwin]

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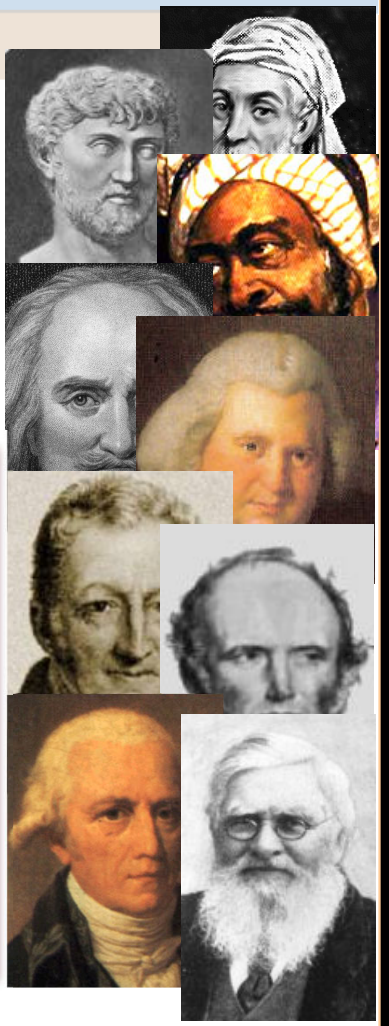
Path to Darwin

- Evolution by natural selection
  - Organisms vary from one another
  - New variation appears from time to time
  - Variation is passed from parent to offspring
  - "struggle for existence" (limited resources)
- Recognized before Darwin
  - Empedocles (490–430 BC)
    - why animals adapt to environment
  - Charles Darwin
    - Evolution, **inevitable**

(Cosma Shalizi citing Aristotle citing) Empedocles:
A difficulty presents itself: why should not nature work, not for the sake of something, nor because it is better so, but just as the sky rains, not in order to make the corn grow, but of necessity? What is drawn up must cool, and what has been cooled must become water and descend, the result of this being that the corn grows. Similarly if a man's crop is spoiled on the threshing-floor, the rain did not fall for the sake of this--in order that the crop might be spoiled--but that result just followed. Why then should it not be the same with the parts in nature, e.g. that teeth should come up of necessity -- the front teeth sharp, fitted for tearing, the molars broad and useful for grinding down the food -- since they did not arise for this end, but it was merely a coincident result; and so with all other parts in which we suppose that there is purpose? **Wherever then all the parts came about just what they would have been if they had come be for an end, such things surourvived, being organized spontaneously in a fitting way; whereas those which grew otherwise perished and continue to perish**, as Empedocles says his 'man-faced ox-progeny' did.



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Path to Darwin

- Evolution by natural selection
  - Organisms vary from one another
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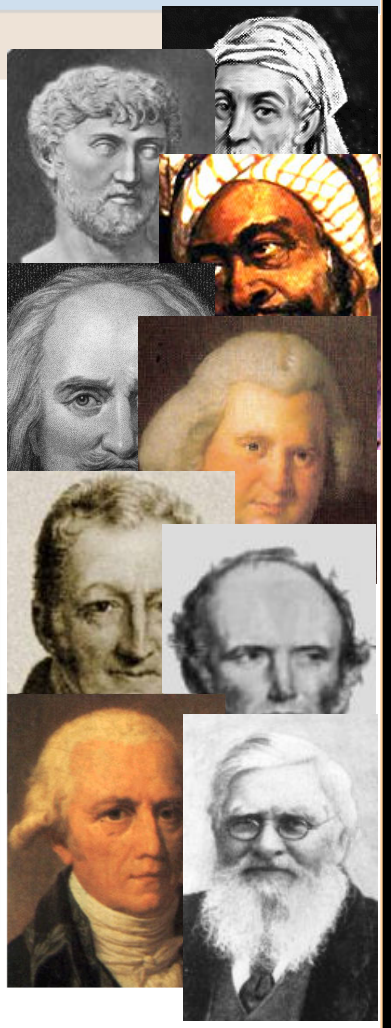
  - Variation is passed from parent to offspring
  - "struggle for existence" (limited resources)
- Recognized before Darwin
  - Empedocles (490–430 BC)
    - why animals adapt to environment
  - Lucretius (99 - 55 BC)
    - Random evolution, free will
  - Reached same conclusion as Darwin (with less evidence)
  - Charles Darwin
    - Evolution, **inevitable**



Lucretius and Epicurism (translated by Stephen Greenblatt):
"... moving randomly through space, like dust motes in a sunbeam, colliding, hooking together, forming complex structures, breaking apart again, in a ceaseless process of creation and destruction. There is no escape from this process. ... There is no master plan, no divine architect, no intelligent design. […] All things, including the species to which you belong, have evolved over vast stretches of time. The **evolution is random**, though in the case of living organisms, it involves **a principle of natural selection**. That is, **species that are suited to survive and to reproduce successfully, endure, at least for a time; those that are not so well suited, die off quickly**. But nothing — from our own species, to the planet on which we live, to the sun that lights our day — lasts forever. Only the atoms are immortal ..."

"I happened to read for amusement Malthus on population, and being well prepared to appreciate the struggle for existence…it at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of new species." [Charles Darwin]

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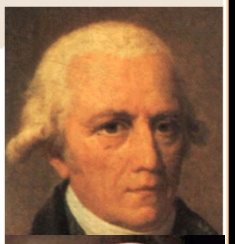
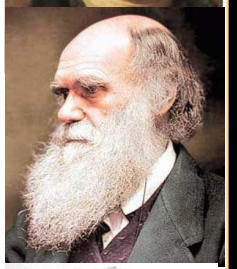
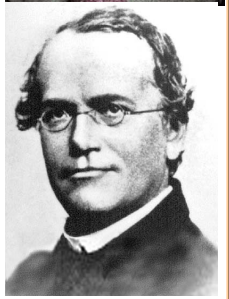
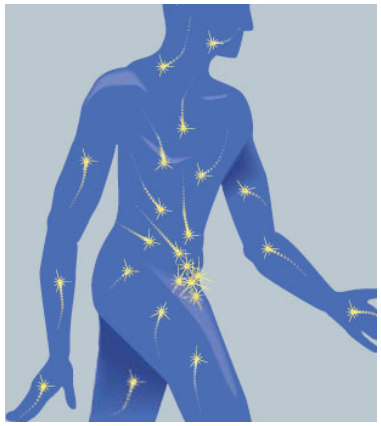
Inheritance mechanism

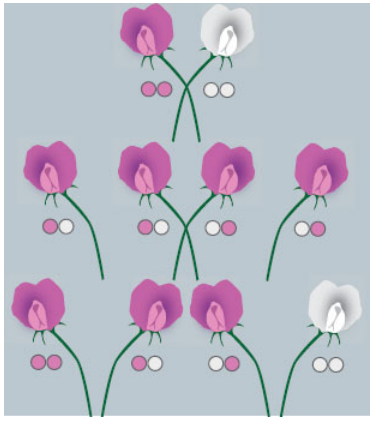






- XIX Century
  - Evolution of species quickly accepted
  - Natural selection as most important engine of change, was not
    - What was the mechanism?
- Jean-Baptiste Lamarck (XIX)
  - mutation and (acquired) inheritance
- Charles Darwin
  - "gemules" ejected from each tissue and traveling to sex organs
- Gregor Mendel
  - discrete factors corresponding to traits
  - Each individual would carry two copies (one from each parent), but only one would be "expressed"
- "Synthesis" only in the XX century





Sci. American, Jan 2009

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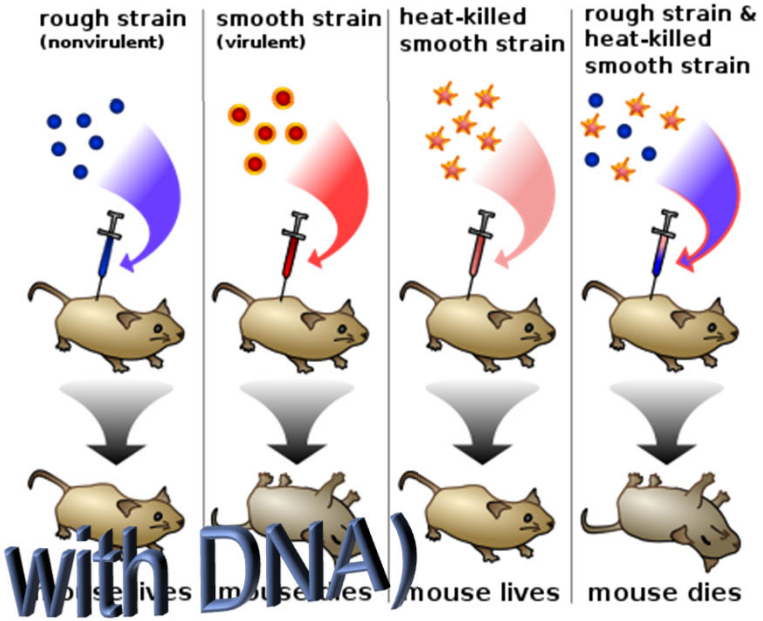
the discovery of the genetic tape

identifying the loci of genetic information

- Frederick Griffith's experiment
  - In 1928: Identified a "transforming principle"
- Avery's experiment
  - Oswald Avery, Colin MacLeod, and Maclyn McCarty
  - 1944: DNA as the loci of "transformation"
    - Chemically knocking off various cellular constituents until trying DNA
    - Considerable resistance in the community accepting this result until the early 1950's (Schrodinger, Delbruck, phage group)

initially not well accepted (No auto-catalysis with DNA)

2 different strains of pneumococcus bacteria



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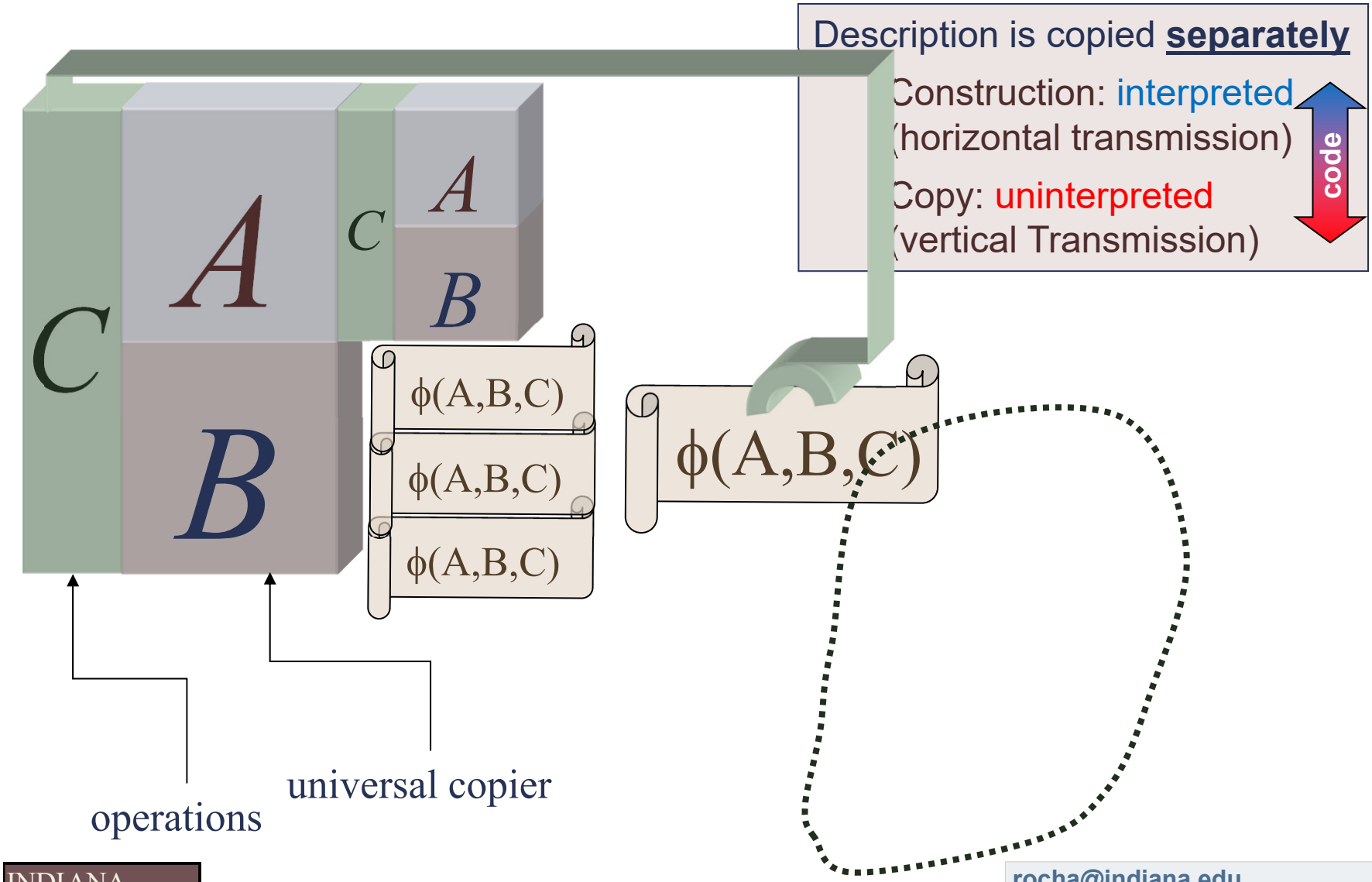
Von Neumann's generalization of Turing's tape

as a general principle (system) of **self-replication**



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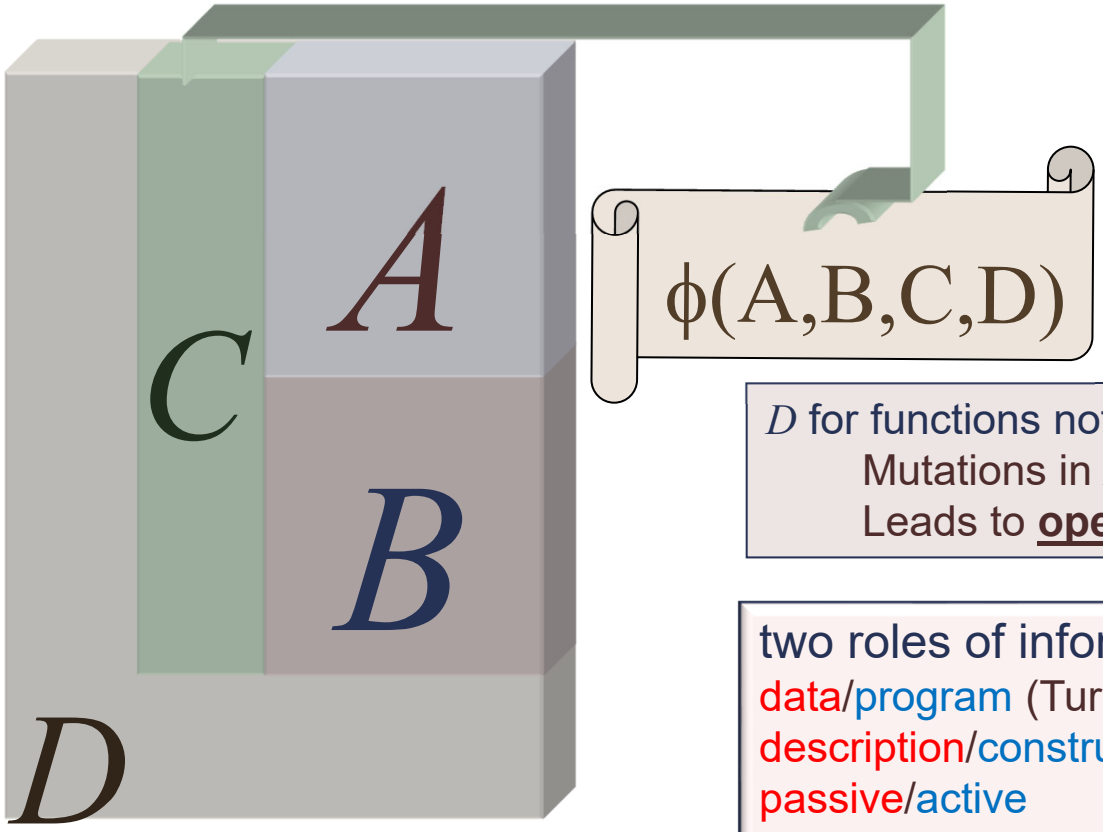
Von Neumann's generalization of Turing's tape

as a general principle (system) of evolution or **open-ended complexity**



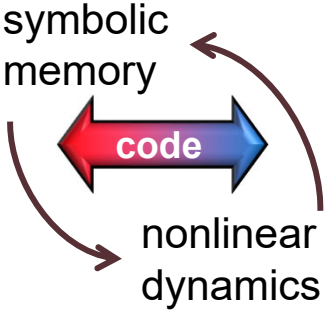
Howard Pattee

D for functions not involved in reproduction
Mutations in *D* can be propagated *vertically*
Leads to **open-ended evolution**

two roles of information
data/program (Turing)
description/construction
passive/active
genotype/phenotype

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

semiotic closure



Pattee, HH [2001] *Biosystems* **60** (1):5-21

Rocha, L.M. & W. Hordijk [2005] *Artificial Life* **11**:189 - 214.
Rocha, L.M. [2001] *Biosystems* **60**: 95-121.
Rocha, L.M. [1996] *Systems Research* **13**: 371-384.

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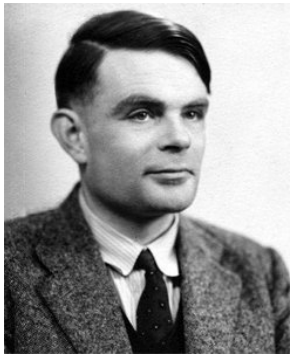
Schrodinger vs. Von Neumann

self-replication vs. decoupled, encoded information



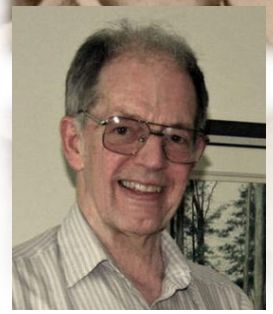
Brenner, Sydney. [2012]. "Life's code script." *Nature* **482** (7386): 461-461.

"Turing invented the stored-program computer, and von Neumann showed that the description is separate from the universal constructor. This is not trivial. Physicist Erwin Schrödinger confused the program and the constructor in his 1944 book *What is Life?,* in which he saw chromosomes as "*architect's plan and builder's craft in one*". This is wrong. The code script contains only a description of the executive function, not the function itself." (Sydney Brenner)

two roles of information
data/program (Turing)
passive/active (Von Neumann)
description/construction-function (Pattee)
genotype/phenotype (Biology)

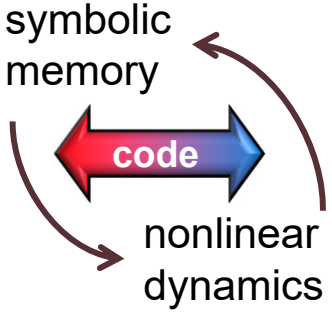
Von Neumann, J. [1949]. "**Theory and organization of complicated automata.**" 5 lectures at University of Illinois

semiotic closure (semiotic coupling)



Howard Pattee

fundamental principle of *organized complexity*
Leads to **open-ended evolution**
General principle that includes *Natural Selection*
Von Neumann described this scheme **before** structure of DNA molecule was identified in 1953 by Watson & Crick



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Rocha, L.M. [2001] *Biosystems* **60**: 95-121.

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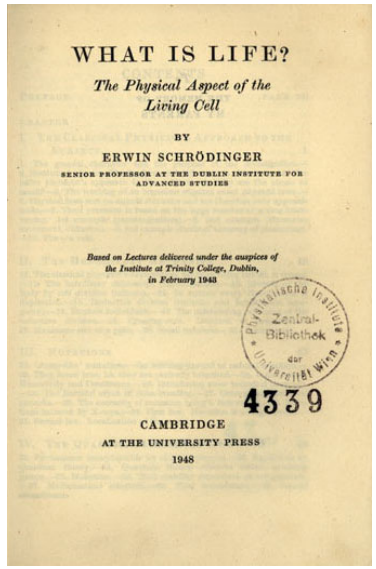
what was known?

Erwin Schrödinger(1943-1944)

- puzzled by the persistence of living structures
  - Call to understand how life stores and perpetuates order
  - "[…] **chromosomes**[…] contain in some kind of **code-script** the entire pattern of the individual's future development."
    - "complete (double) copy of the code-script."
- **aperiodic crystals (replicator structures)**
  - "We believe a gene—or perhaps the whole chromosome **fiber**—to be an aperiodic solid."
    - "structure without predictable repetition"
  - DNA is entirely regular
    - Instead of "aperiodicity" we have **encoded information**: separated description/construction



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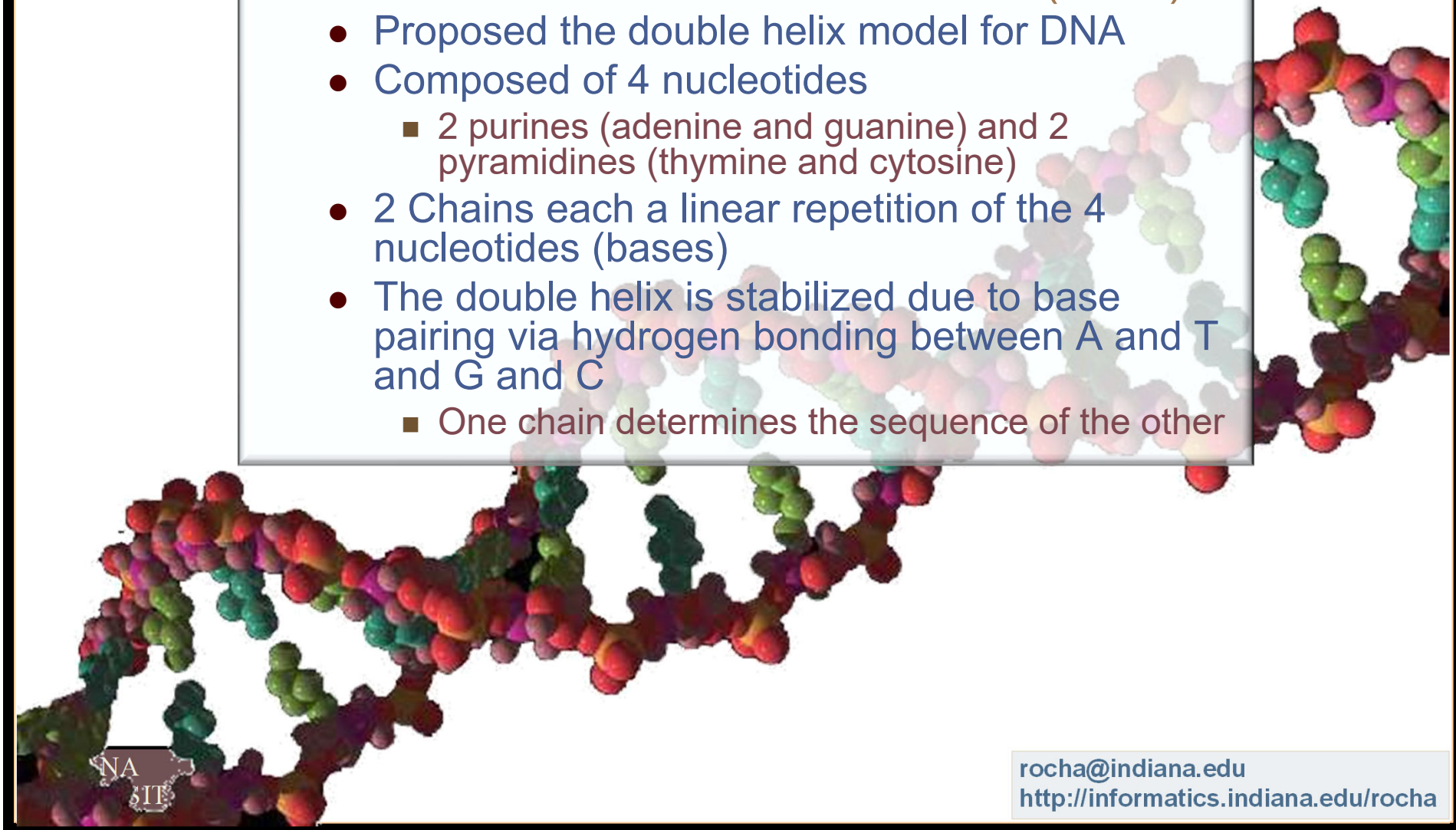
DNA

deoxyribonucleic acid

- The chromatin contains DNA and protein
- James Watson and Francis Crick (1953)
  - Proposed the double helix model for DNA
  - Composed of 4 nucleotides
    - 2 purines (adenine and guanine) and 2 pyramidines (thymine and cytosine)
  - 2 Chains each a linear repetition of the 4 nucleotides (bases)
  - The double helix is stabilized due to base pairing via hydrogen bonding between A and T and G and C
    - One chain determines the sequence of the other



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a molecular language system: nucleotide “bases”

Purine (R) → Adenine (A), Guanine (G)

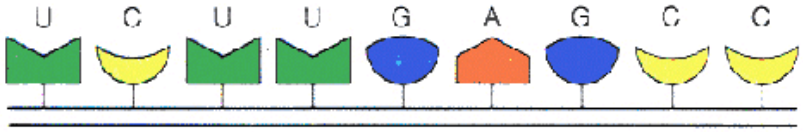
Nucleotides

Pyrimidine (Y) → Cytosine (C), Thymine (T), Uracil (U)

4 Letter Alphabet
DNA: A, G, C, T
RNA: A, G, C, U

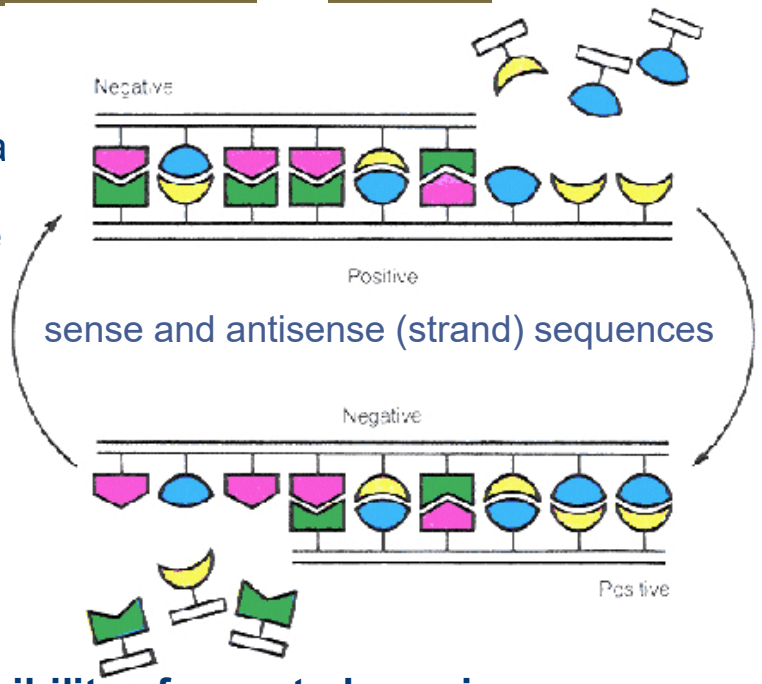
Form sequences that can store information

Linear molecules with a phosphate-sugar backbone (deoxyribose and ribose)



Complementary base pairing
(Hydrogen-bonding between purines and pyrimidines)

A-T (U) G-C



sense and antisense (strand) sequences

Requirements for structural information

Possibility of repeated copying

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Figures from Eigen [1992] . *Steps Towards Life*.

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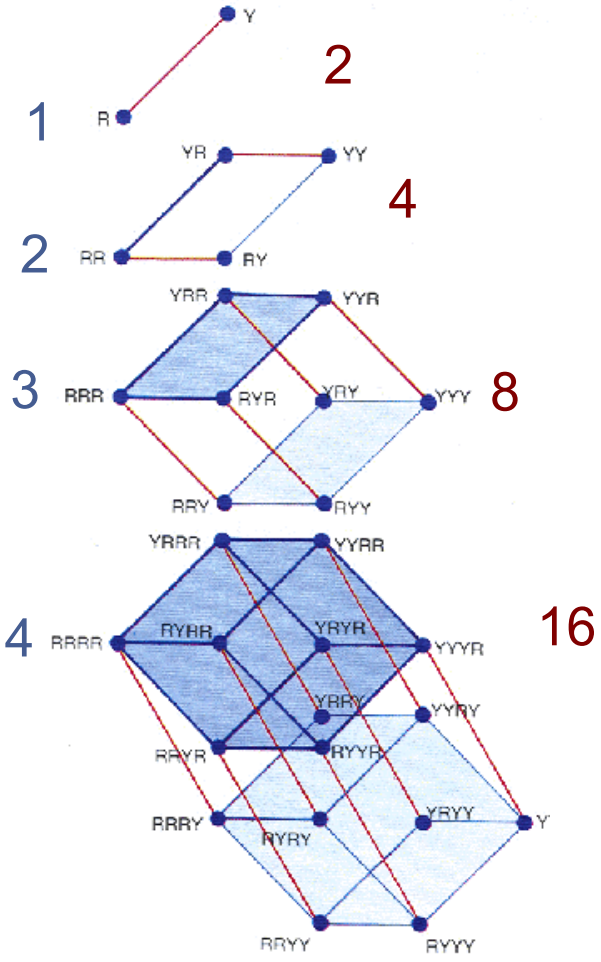
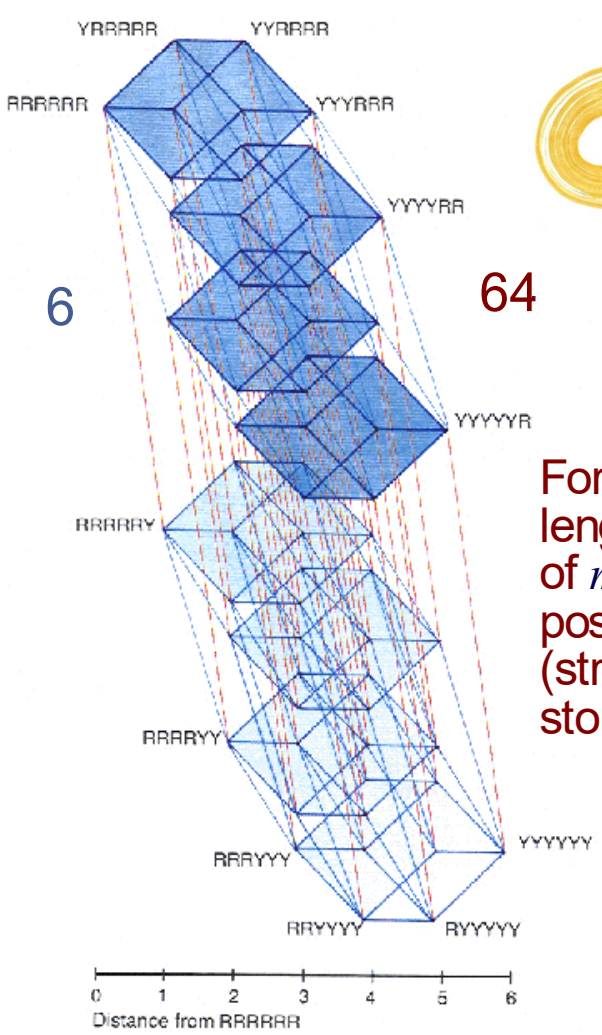
Information and Sequence Space





For a sequence of length n, composed of m-ary symbols, m^n possible values (structures) can be stored

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Figures from Eigen [1992] . *Steps Towards Life*.

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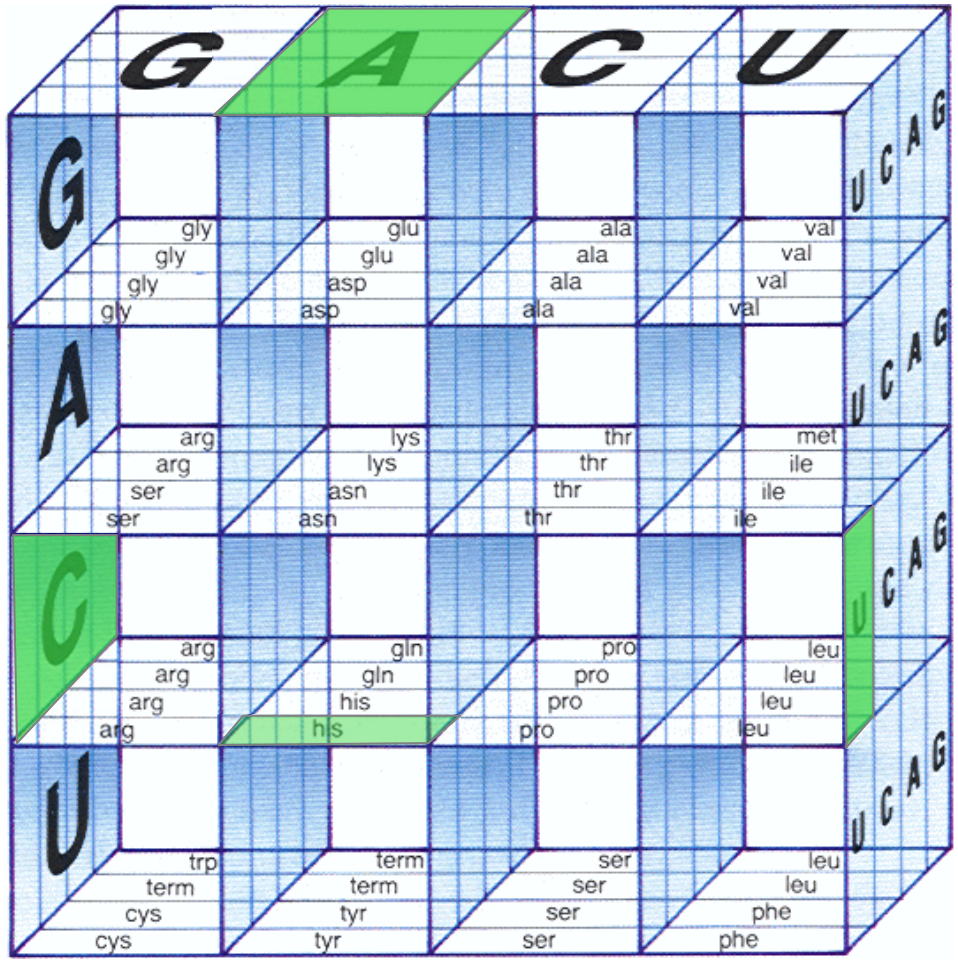
The Genetic Code

- The genetic code maps information stored in the genome into functional proteins
  - Triplet combinations of nucleotides into amino acids



Triplets of 3 Nucleotides can define 64 possible codons, but only 20 amino acids are used (redundancy)

Figures from Eigen [1992] . *Steps Towards Life*.

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functional products

Polypeptide chains of aminoacids

Primary Structure

Folding

3-dimensional structure

Secondary and tertiary bonds

- In proteins, it is the 3-dimensional structure that dictates function
  - The specificity of enzymes to recognize and react on substrates
- The functioning of the cell is mostly performed by proteins
  - Though there are also ribozymes

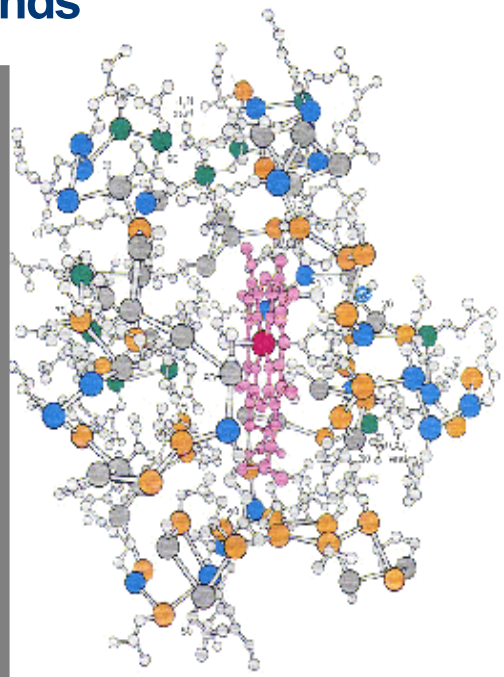

Table 1.4. Amino acid codes

Ala	A	Alanine
Arg	R	Arginine
Asn	N	Asparagine
Asp	D	Aspartic acid
Cys	C	Cysteine
Gln	Q	Glutamine
Glu	E	Glutamic acid
Gly	G	Glycine
His	H	Histidine
Ile	I	Isoleucine
Leu	L	Leucine
Lys	K	Lysine
Met	M	Methionine
Phe	F	Phenylalanine
Pro	P	Proline
Ser	S	Serine
Thr	T	Threonine
Trp	W	Tryptophan
Tyr	Y	Tyrosine
Val	V	Valine
Asx	B	Asn or Asp
Glx	Z	Gln or Glu
Sec	U	Selenocysteine
Unk	X	Unknown

Figures from Eigen [1992] . *Steps Towards Life*.

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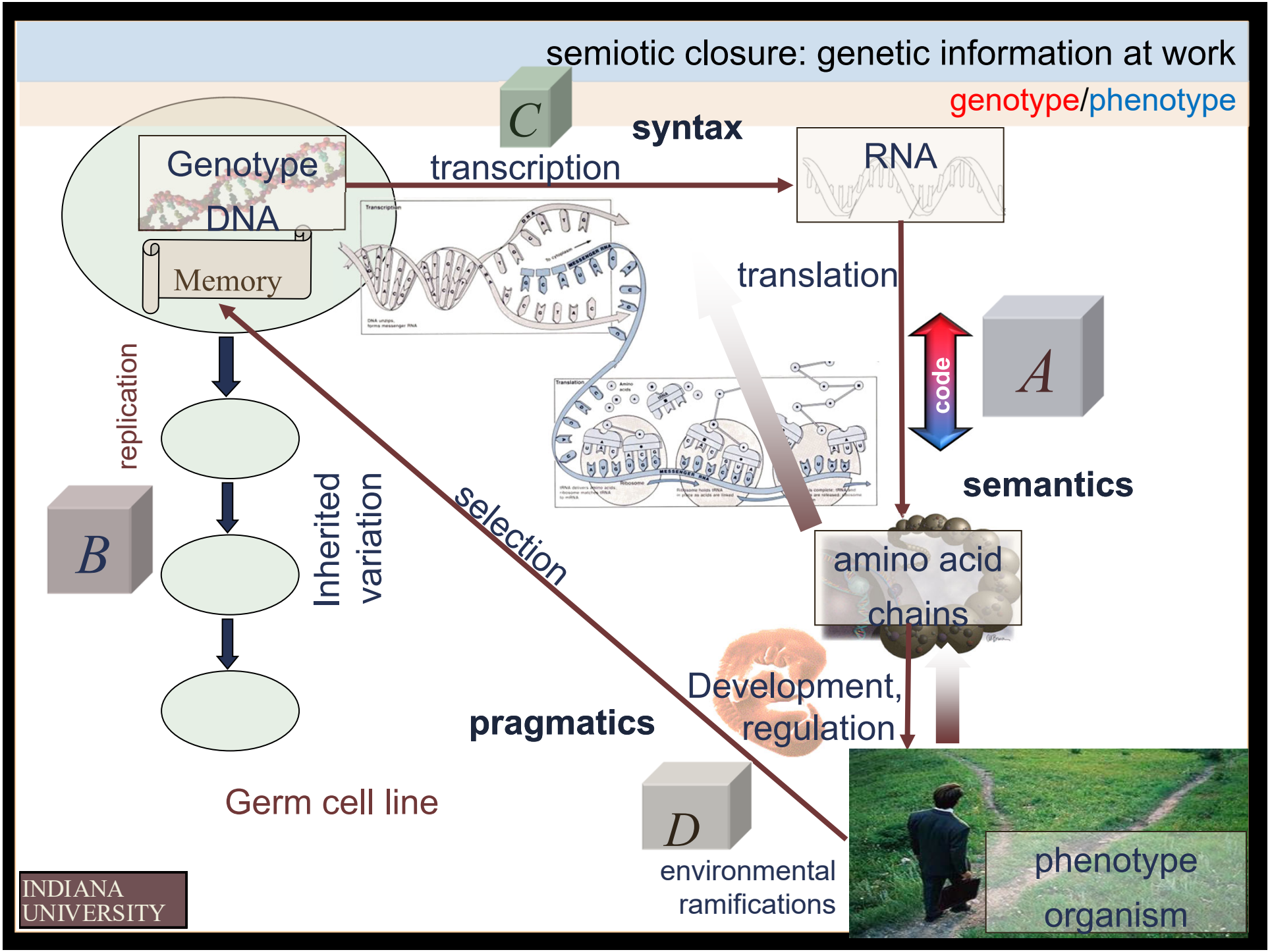
semiotic closure: genetic information at work
genotype/phenotype
C
syntax
Genotype
DNA
Memory
transcription
RNA
translation
code
A
semantics
replication
B
Inherited variation
selection
amino acid chains
Development, regulation
pragmatics
Germ cell line
D
environmental ramifications
phenotype organism
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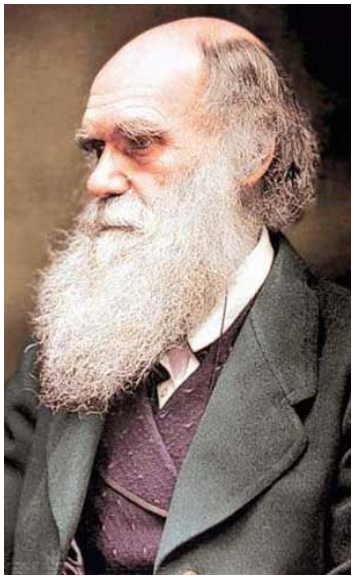
fundamental principle of organisms as *informatic mechanisms*



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