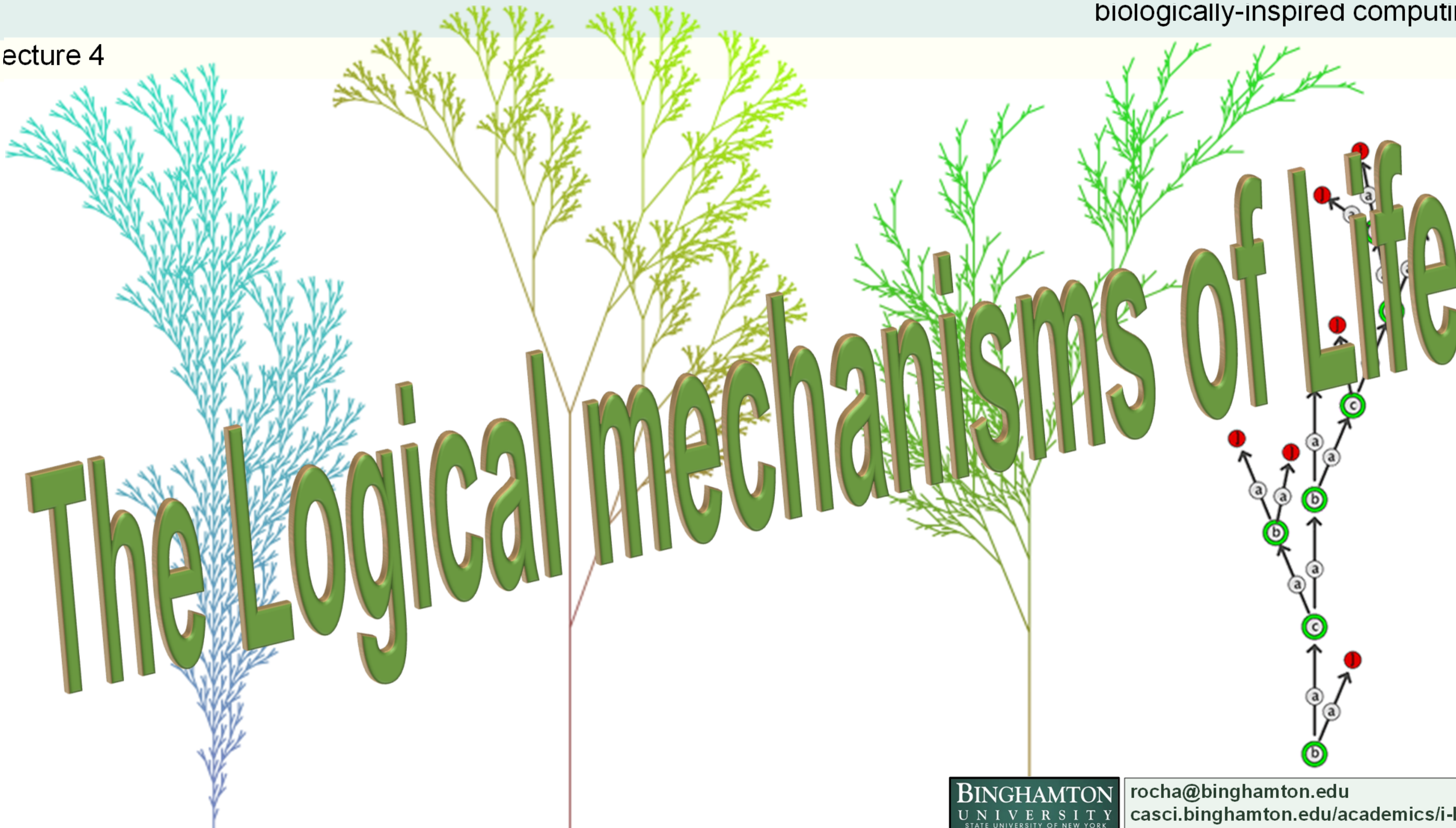
The Logical mechanisms of Life



Binghamton University, State University of New York
rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

evolutionary systems and biologically-inspired computing

Resources
- web page
  - casci.binghamton.edu/academics/i-bic/
- online class
  - Link on Brightspace
- blog: life inspired
  - life-inspired.blogspot.com
- Brightspace
  - brightspace.binghamton.edu/d2l/home/305125

ISE-483/SSIE-583 - spring 2024

luis m. rocha

bit.ly/atBIC

office hours:
thursdays 9:00- 11:30am, EB S04
binghamton.zoom.us/my/luismrocha

office hours:
mondays and wednesdays:10:30 am to 1:00 pm
EB K1 and zoom link on Brightspace

rocha@binghamton.edu
casci.binghamton.edu/academics/i-bic

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key events coming up

- Labs: 35% (ISE-483)
  - Complete 5 (best 4 graded) assignments based on algorithms presented in class
    - Lab 0 : January 29th
      - *Introduction to Python* (No Assignment)
        - Delivered by SSIE583 Group 2
          - see solved exercises!
    - Lab 1 : February 5th
      - *Measuring Information* (Assignment 1)
        - Delivered by SSIE583 Group 3
        - Due: February 12th
    - Lab 2 : February 19th
      - *L-Systems* (Assignment 2)
        - Delivered by SSIE583 Group 1
        - Due: February 26th
- SSIE – 583 -Presentation and Discussion: 25%
  - Present and lead the discussion of an article related to the class materials
    - Enginet students post/send video or join by Zoom
  - Dates TBA
    - Kauffman, S.A. [1969]. "Metabolic stability and epigenesis in randomly constructed genetic nets". Journal of Theoretical Biology 22(3):437-467.
      - Presented by Yoshiaki Fujita
    - Stanley, Kenneth O., Jeff Clune, Joel Lehman, and Risto Miikkulainen. “Designing Neural Networks through Neuroevolution.” Nature Machine Intelligence 1, no. 1 (January 2019): 24–35.
      - Presented by Jessica Lasebikan
    - Discussion by all

rocha@indiana.edu
casci.binghamton.edu/academics/i-bic

readings

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press. **Preface**.
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall. **Chapter 1**, pp. 1-23.
- Lecture notes
  - Chapter 1: "What is Life?"
  - Chapter 2: The logical Mechanisms of Life
    - posted online @ http://informatics.indiana.edu/rocha/i-bic

- Papers for Presentations
  - Logical mechanisms of life (optional for SSIE 483)
    - Langton, C. [1989]. "Artificial Life" In *Artificial Life*. C. Langton (Ed.). Addison-Wesley. pp. 1-47.
      - Pattee, H. [1989], "Simulations, Realizations, and Theories of Life". In Artificial Life. C. Langton (Ed.). pp. 63-77
- Other Readings
  - Optional
    - Gleick, J. [2011]. *The Information: A History, a Theory, a Flood*. Random House. **Chapter 8**.
    - Cobb, Matthew. [2013]. "1953: When Genes Became 'Information'." *Cell* **153** (3): 503-506.
    - Aleksander, I. [2002]. "Understanding Information Bit by Bit". In: *It must be beautiful : great equations of modern science*. G. Farmelo (Ed.), Grant
    - James, R., and Crutchfield, J. (2017). Multivariate Dependence beyond Shannon Information. Entropy, 19(10), 531.
    - Prokopenko, Mikhail, Fabio Boschetti, and Alex J. Ryan. "An information-theoretic primer on complexity, self-organization, and emergence." Complexity 15.1 (2009): 11-28.

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Spring 2024 Evolutionary Sys & Bio-Ins... | Luis Rocha

Course Home | Calendar | Content | Assignments | Quizzes | Discussions | Evaluation | Classlist | Course Tools | Help

Syllabus / Overview
Bookmarks
Course Schedule

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Syllabus
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Class Recordings
Lecture Slides and Other Materials
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Readings

Print | Settings

Add dates and restrictions...

See all class readings at: https://casci.binghamton.edu/academics/i-bic/index.php#material

Class Book

- Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press. Available in electronic format for SUNY students.
  - Nunes de Castro, Leandro [2006]. Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications. Chapman & Hall. Chapter 1, pp. 1-23.

Lecture notes

- 1. What is Life?

Articles

- Dennet, D.C. [2005]. "Show me the Science". *New York Times*, August 28, 2005
- Polt, R. [2012]. "Anything but Human". *New York Times*, August 5, 2012

Optional Readings

- Gleick, J. [2011]. *The Information: A History, a Theory, a Flood*. Random House. Chapter 8.
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how much is specific bio-chemistry and history?

- Can there be several implementations of life?
  - To study life do we need to find and synthesize the necessary threshold of complexity?
    - Hard Artificial Life
  - Or is it enough to simulate the behavior of life?
    - Soft Artificial Life
  - What about implementing “new” life in known biochemistry
    - Wet Artificial Life or Synthetic Biology
- Important to study the living organization
  - What can be abstracted and implemented in a different medium?
  - Understanding <u>organization</u> and <u>design principles</u>
    - Scientific advancement of the fundamental principles of life
      - Systems and Computational Biology , Artificial Life, Evolutionary Systems
    - Solving engineering and design problems
      - Bio-inspired computing

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life-as-it-could-be

- Chris Langton
  - **Artificial Life** can contribute to theoretical biology by locating *life-as-we-know-it* within the larger picture of *life-as-it-could-be*
  - life as a property of the *organization* of matter, rather than a property of the matter which is so organized
    - The way information is processed
  - Whereas biology has largely concerned itself with the material basis of life, Artificial Life is concerned with the formal basis of life.
    - views an organism as a large population of *simple* machines
    - *Synthetic approach* or *emergent behavior*

Langton, C. [1989]. “Artificial Life” In: *Artificial Life*. C. Langton (Ed.). Addison-Wesley. pp. 1-47.

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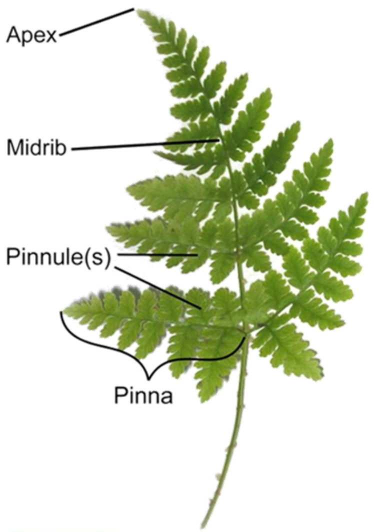
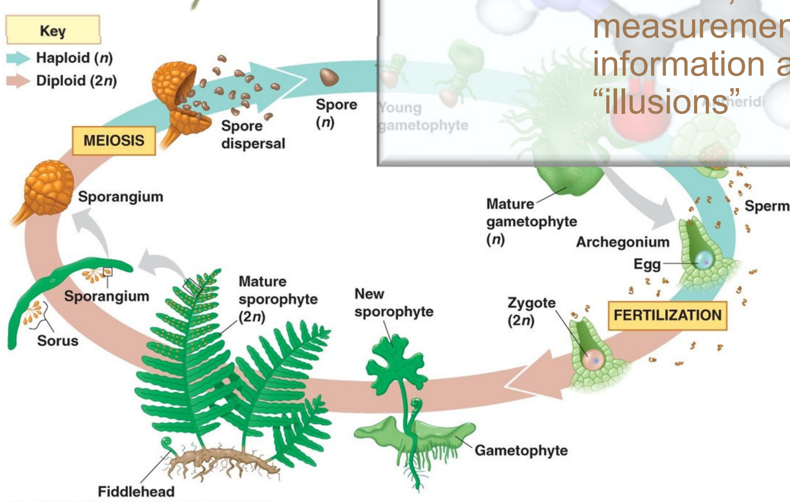
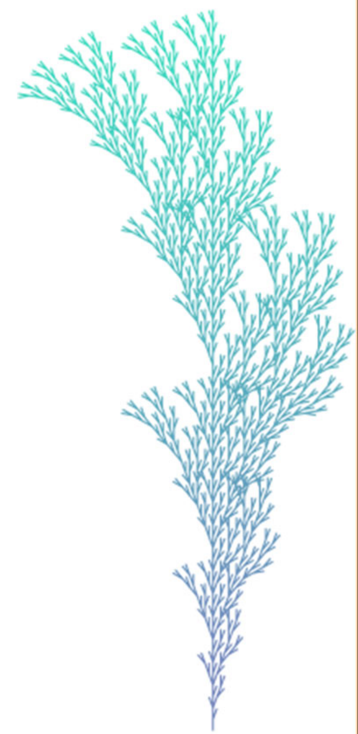
alternative concepts of mechanism



- Analytical
  - Reduction to (non-living) components
    - Reductionism
  - ***Material*** mechanism
  - Life is complicated chemistry
  - Tied to specific materiality
  - Does not allow emergence (in a radical "strawman" view)
    - Function, control, measurement, categorization, information are unnecessary "illusions"

- Synthetic
  - Construction from components
    - Holist
  - ***Logical*** mechanism
  - Life is **Organization**
    - **Networks of components**
  - Universal or implementation independent
  - Emergence
    - "bottom-up" approach





Axiom: F
F = F[+F]F[-F][F]
Order 5
Angle 20

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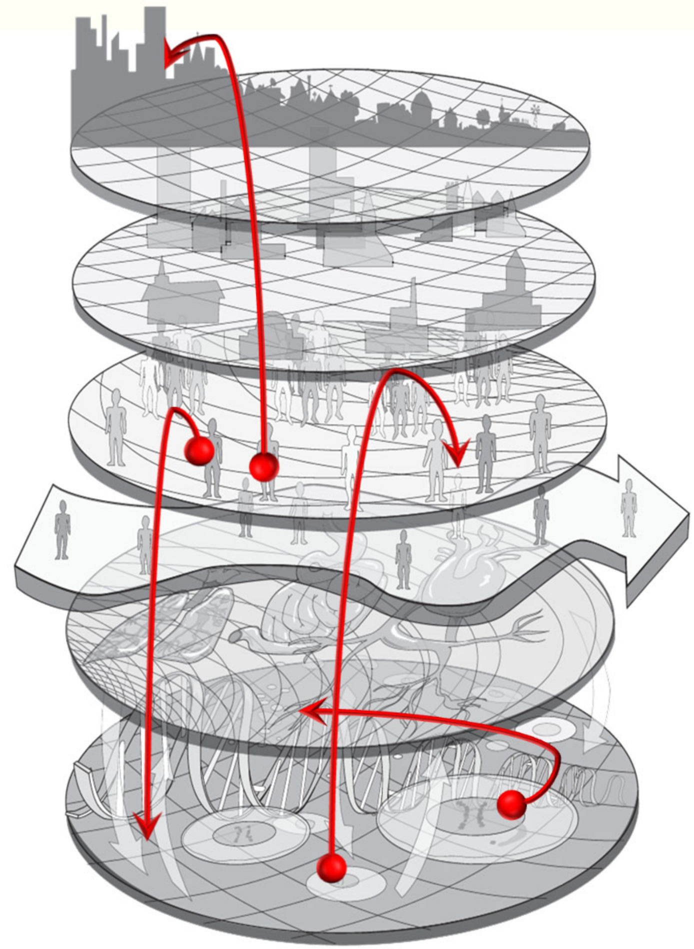
complexity threshold

- Science often sees life as the complicated physics of a collection of moving bodies
  - Reductionist search for answers in the nitty-gritty of biochemistry
    - Separable variables or near-decomposable modules (Simon)
  - When do we reach a threshold of complexity after which matter is said to be living?
    - Which variables, networks, components, relations must be included?
- Life as (emergent) organization
  - Systems Thinking
    - Ludwig von Bertallanfy (1980)
    - What is important are not the actual physical components but the relations amongst them
  - But what about evolution and history?
    - Conflict between (general) organization and specific components with their history
    - What organization explains evolution?

"Seeking a connecting link, they had condescended to the preposterous assumption of structureless living matter, unorganized organisms, which darted together of themselves in the albumen solution, like crystals in their mother-liquor; yet organic differentiation still remained at once condition and expression of all life. **One could point to no form of life that did not owe its existence to procreation by parents**". Thomas Mann [1924].



Pescosolido, B.A. 2006. Journal of Health and Social Behavior 47:189-208.

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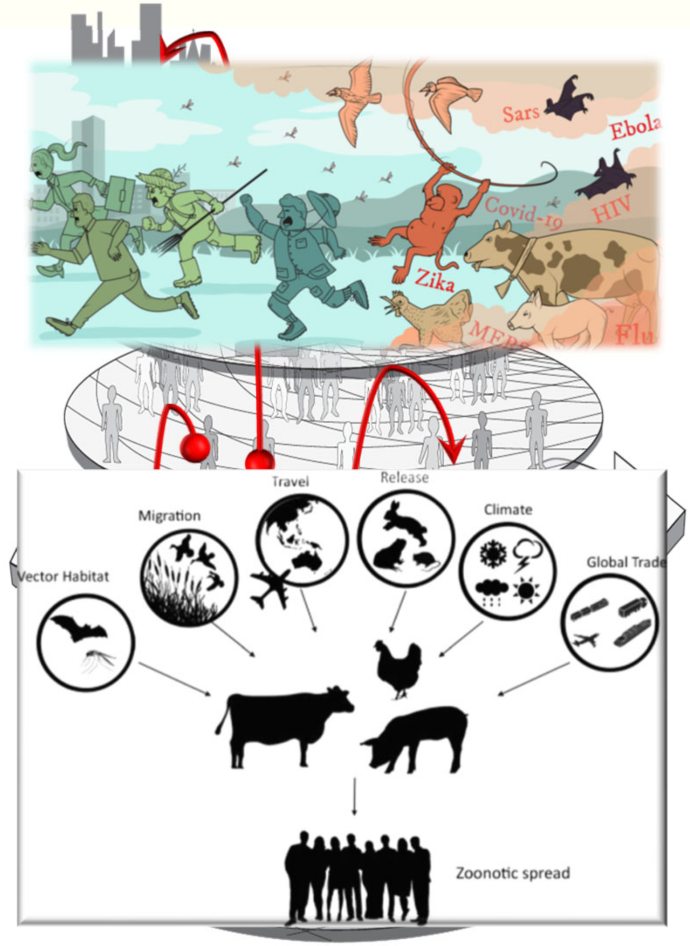


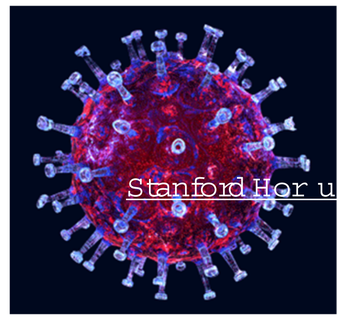
Pescosolido, B.A. 2006. Journal of Health and Social Behavior 47:189-208.

how to identify it?

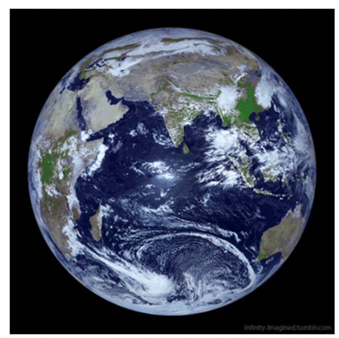
- List of properties
  - Growth
  - Metabolism
  - Reproduction
  - Adaptability
  - Self-maintenance (autonomy)
  - Self-repair
  - Self-assembly
  - Reaction
  - Evolution
  - Choice
- Threshold of complexity
  - Closure (metabolic, functional)
    - Categorization and Control
    - Function (self-reference)
  - Open-ended evolution
  - (genomic) Information

Is life Fuzzy?

Is there a synthetic criteria? How general can it be?



viruses
candle flames
the Earth
hurricanes
robots
self-assembling wires?



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rocha@indiana.edu
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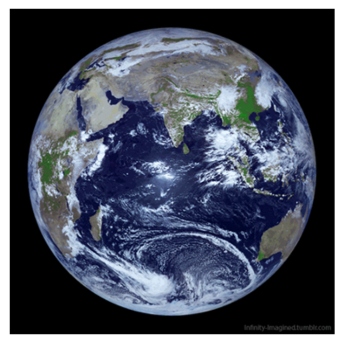

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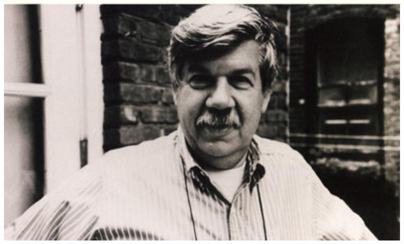
interplay between micro- and macro-level behavior

- Life as emergent organization
  - impossibility of epistemological reduction of the properties of a system to its components
    - Whole is more than sum of parts
      - “Clockness”: many possible material implementations
      - Several biological designs for similar function (e.g. flying)
      - The function of DNA does not lie in its dynamic (bio-chemical) characteristics
    - Crux of complexity
      - Micro- vs. macro-level descriptions
  - Caveat
    - Information and function are contextual and historical
- How to understand/design matter and organization?
  - Is systems thinking dualistic? Neo-vitalism?
  - Complementarity: wave-particle duality



“First, nothing in biology contradicts the laws of physics and chemistry; any adequate biology must be consonant with the ‘basic’ sciences. Second, the principles of physics and chemistry are not sufficient to explain complex biological objects because new properties emerge as a result of organization and interaction. These properties can only be understood by the direct study of the whole, living systems in their normal state. Third, the insufficiency of physics and chemistry to encompass life records no mystical addition, no contradiction to the basic sciences, but only reflects the **hierarchy** of natural objects and the principle of ***emergent properties*** at higher levels of organization”. Stephen Jay Gould

Howard Pattee

Robert Rosen

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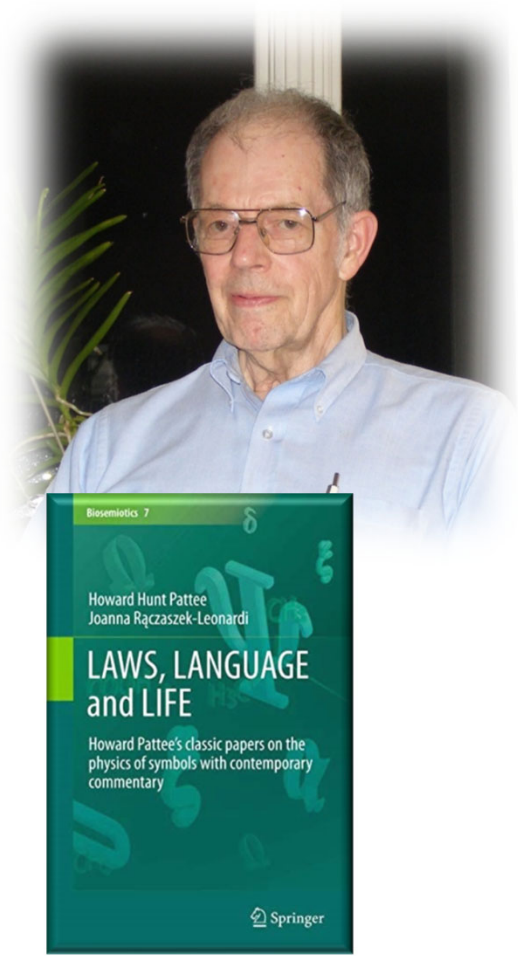
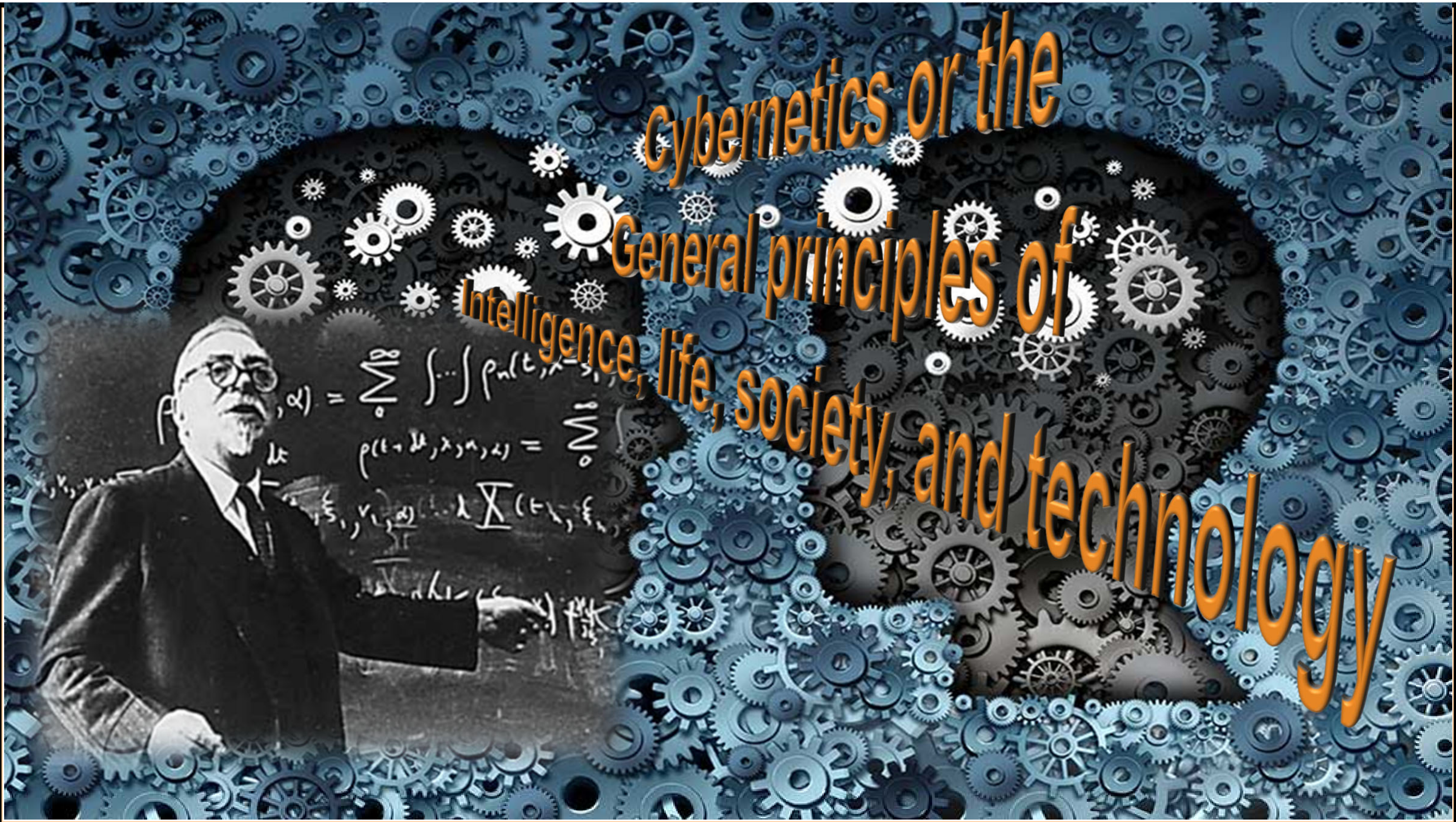
criteria for deciding good simulations or realizations?



- Alife must be compared to something
  - What is the formal/logical threshold of complexity?
    - **Hard Alife** must provide a set of rules to distinguish Alife from artificial matter
    - **Weak Alife** needs to be able to test design principles of life with simulations
      - **Bio-inspired computing** needs only to produce good results in engineering problems
  - Comparison to "life-like" behavior is too subjective
- theories of life
  - Alife methodology requires existing theories of life to be compared against
    - constrained by (rather than freed from) our theories or "fiction"
  - contributes to the meta-methodology of Biology
    - test and improve beyond material constraints, such as the incomplete fossil record or measurement of cellular activity

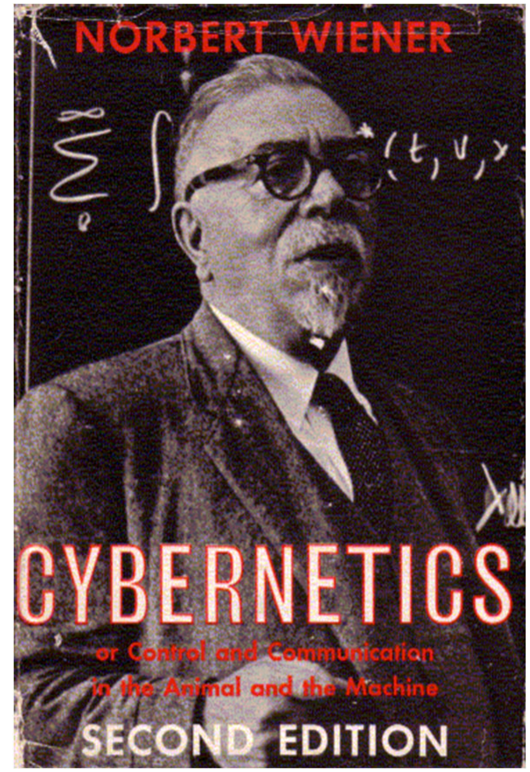
Pattee, H. [1989], "Simulations, Realizations, and Theories of Life". In *Artificial Life*. C. Langton (Ed.) Addison-Wesley. pp. 63-77.



Cybernetics or the
General principles of
Intelligence, life, society, and technology

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)



Warren S. McCulloch

Margaret Mead

Claude Shannon

Heinz Von Foerster

Walter Pitts

Macy Conferences: 1946-**53**

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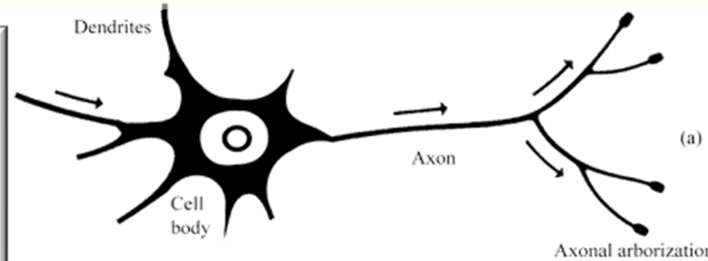
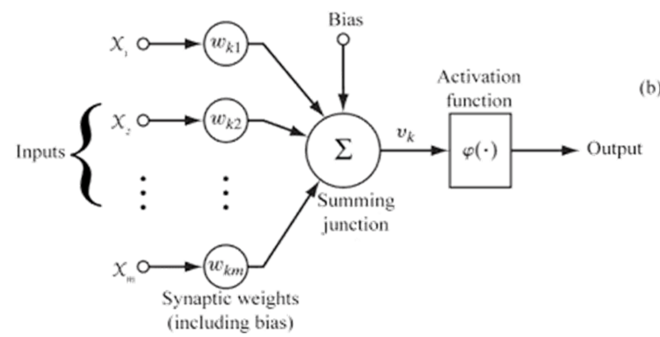
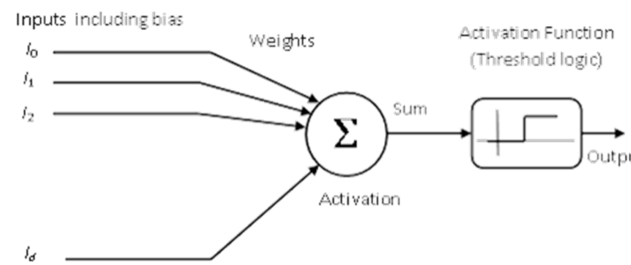
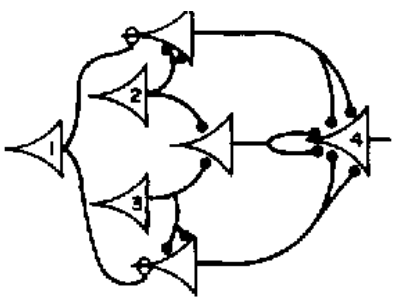
Memory can be maintained in circular networks of binary switches

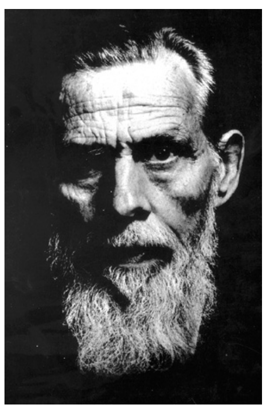
- McCulloch, W. and W. Pitts [1943], "A Logical Calculus of Ideas Immanent in Nervous Activity". *Bulletin of Mathematical Biophysics* **5**:115-133.
  - A Turing machine program could be implemented in a finite network of binary neuron/switches
    - Neurons as basic computing unit of the brain
   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

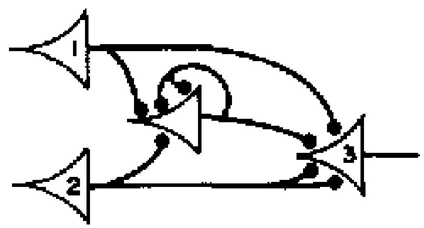












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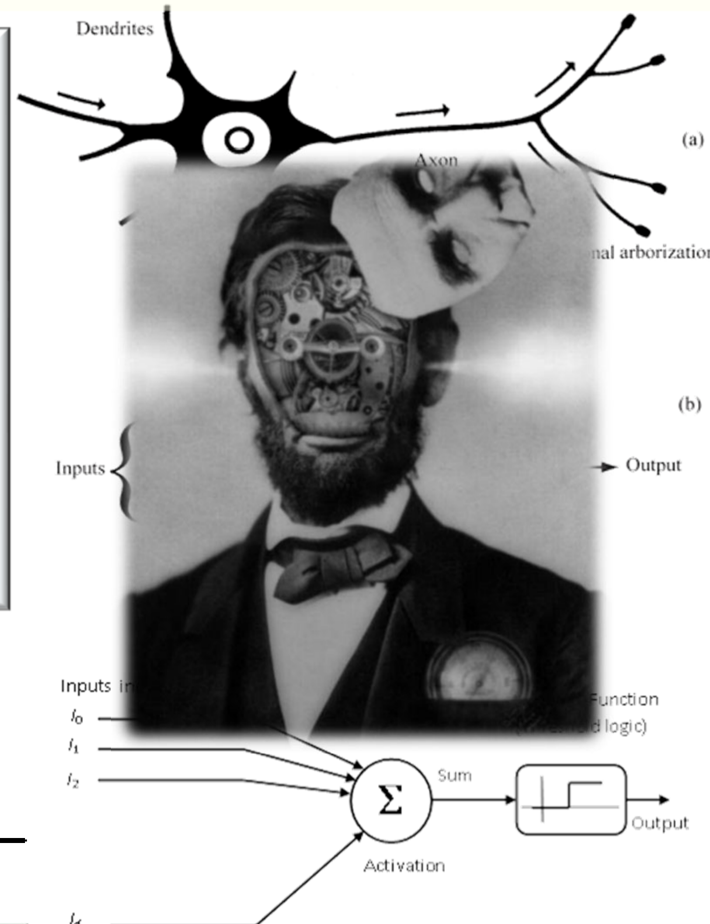

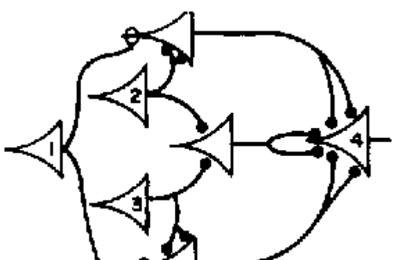

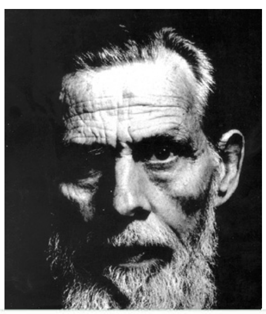

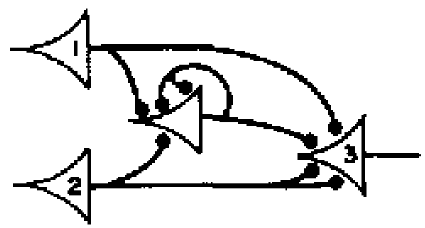

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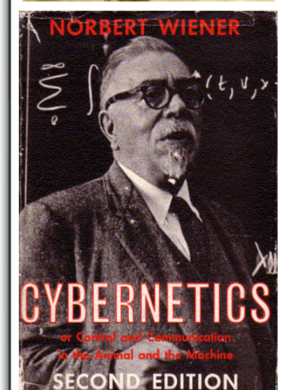
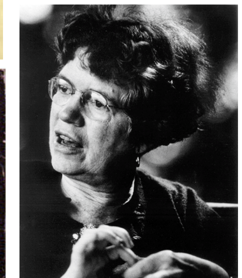
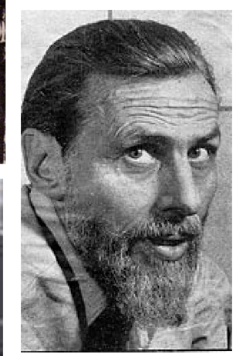
universal computers and general-purpose mechanisms

- 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 and organization







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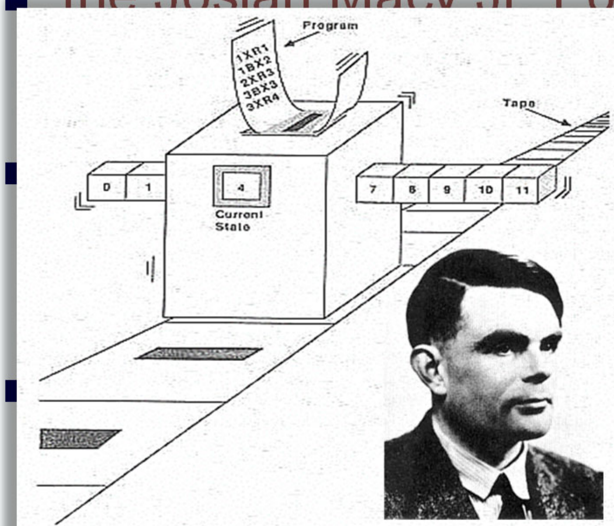
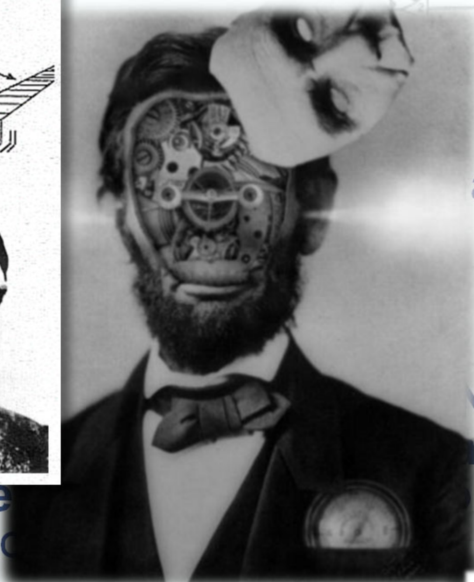
- the Josiah Macy Jr. Foundation Meetings





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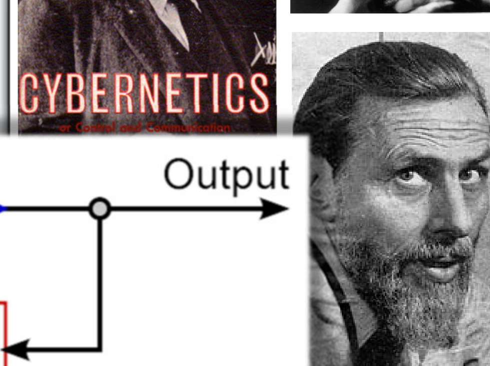

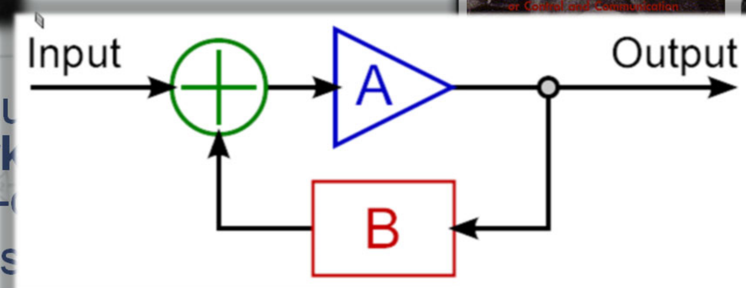

- Key concepts
  - **universal computation** (Turing, Von Neu **information** (Shannon, Wiener), **network** homeostasis, **feedback**, complexity, self-
  - mind, society, life as general mechanisms

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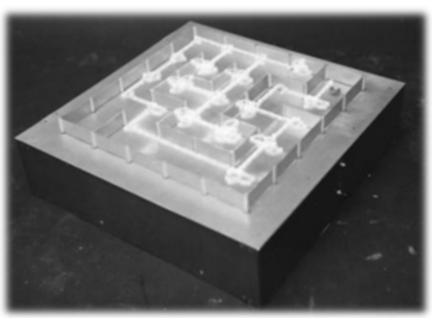
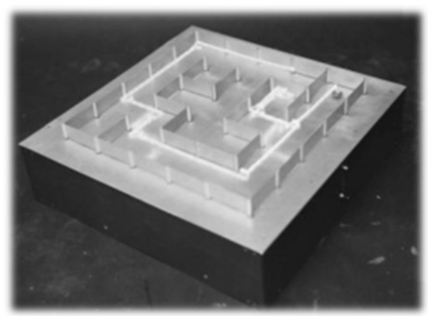
Shannon's mouse

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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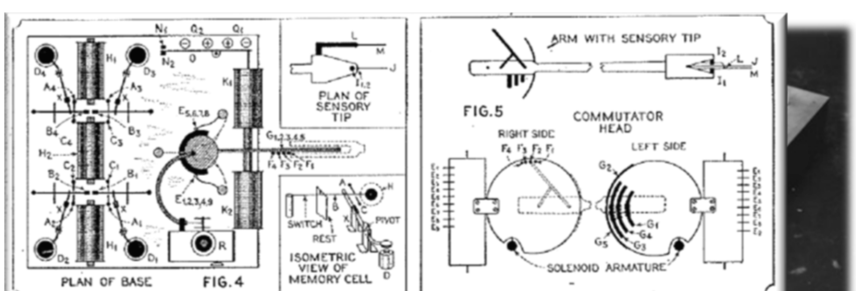
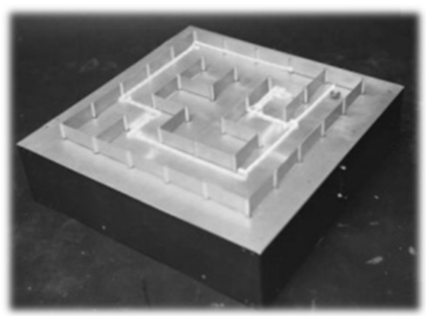


Details of the various parts of the "memory cells" and actuating mechanisms



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Shannon’s mouse

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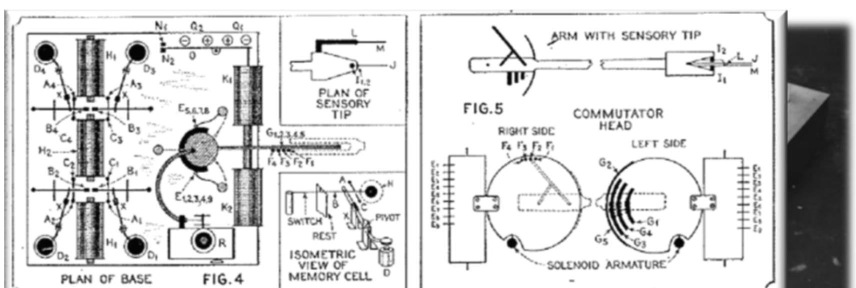

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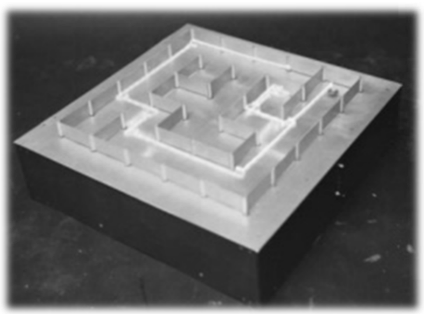

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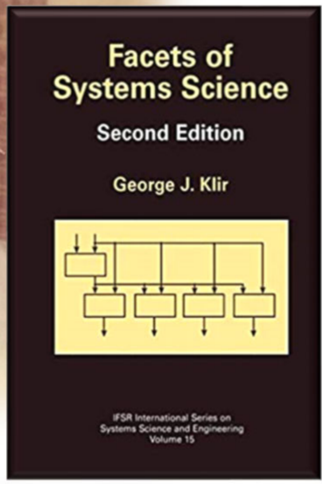
a science of *organization* across disciplines

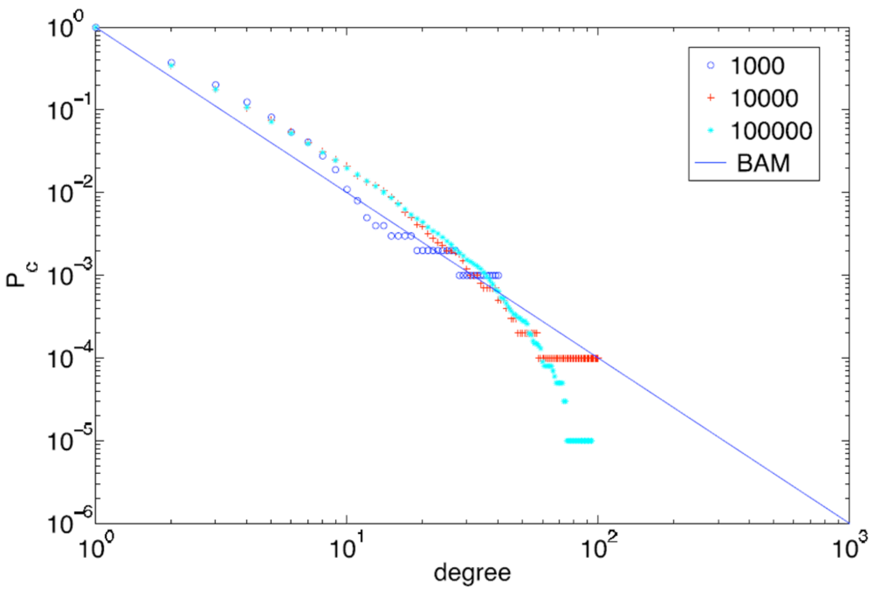
- Systemhood properties of nature
  - Robert Rosen
    - Systems depends on a specific adjective: **thinghood**
    - **Systemhood**: properties of arrangements of items, independent of the items
      - Similar to "setness" or cardinality
  - George Klir
    - **Organization** can be studied with the mathematics of **relations**
    - $S = (T, R)$
      - S: a System, T: a set of things(thinghood), R: a (or set of) relation(s) (Systemhood)
      - Same relation can be applied to different sets of objects
      - Systems science deals with **organizational properties** of systems independently of the items
    - Examples
      - Collections of books or music files are sets of things
      - But organization of such sets are systems (alphabetically, chronologically, typologically, etc.)

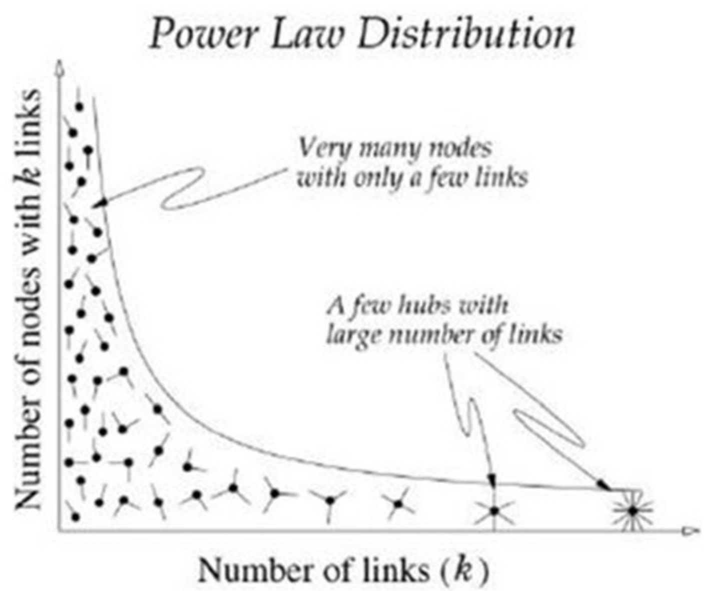


example of general principle of organization

Barabasi-Albert Model: leads to power-law node degree distributions in networks

Amaral et al: Most real networks have a cut-off distribution for high degree nodes which can be computationally modeled with vertex aging.





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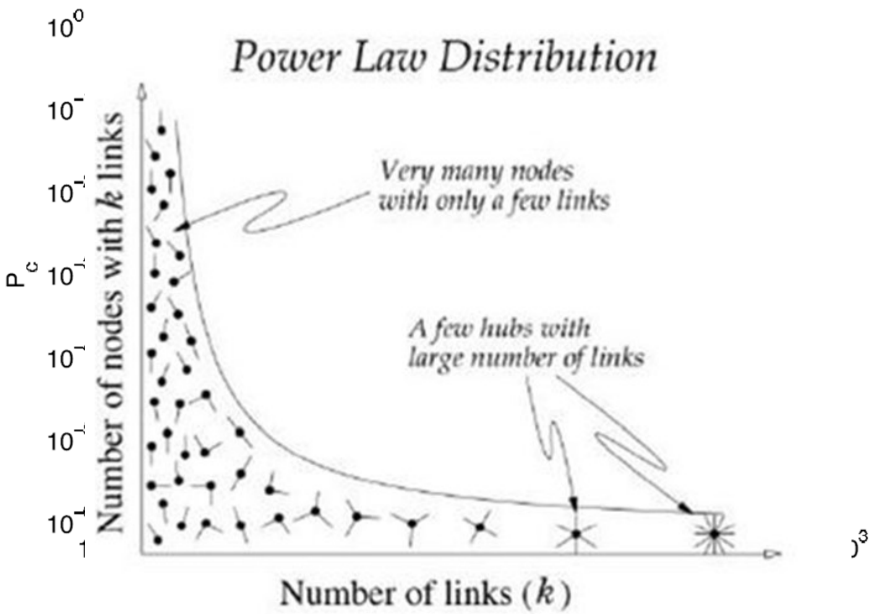

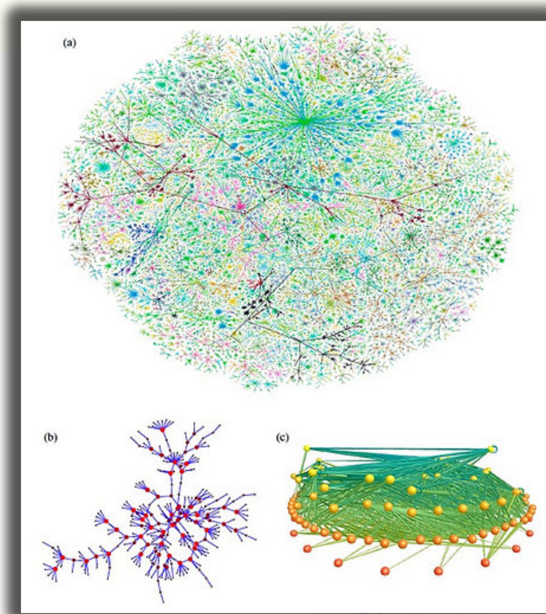

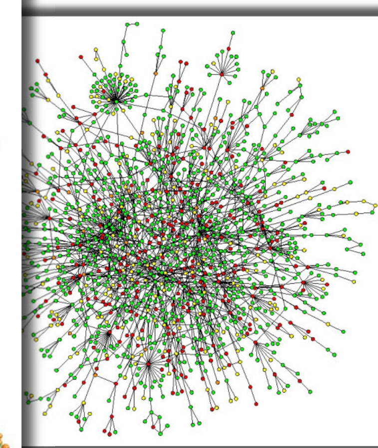

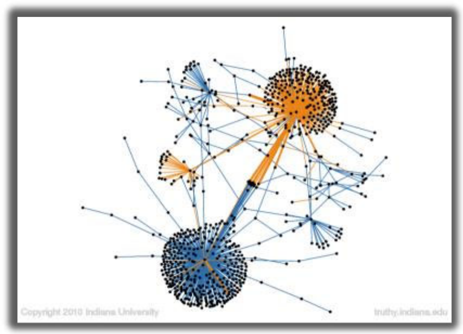

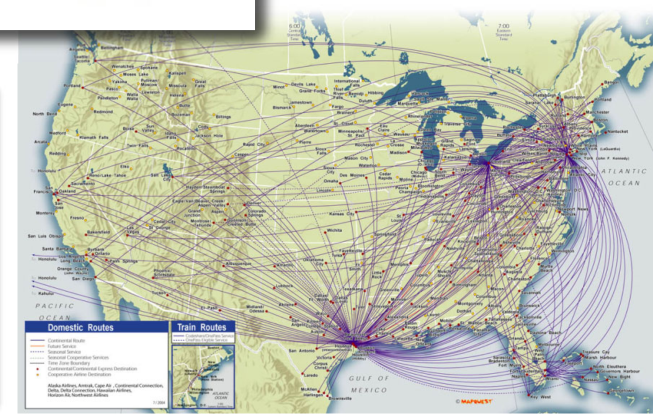

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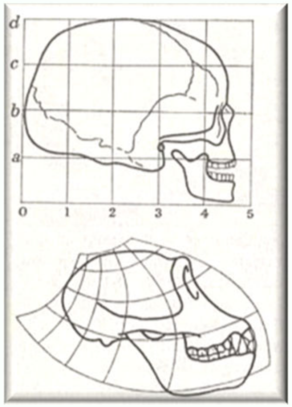
Next lectures

readings

- Class Book
  - Floreano, D. and C. Mattiussi [2008]. *Bio-Inspired Artificial Intelligence: Theories, Methods, and Technologies*. MIT Press. **Preface, Sections 4.1, 4.2**.
    - Nunes de Castro, Leandro [2006]. *Fundamentals of Natural Computing: Basic Concepts, Algorithms, and Applications*. Chapman & Hall. **Chapter 1,** pp. 1-23. Chapter 7, sections **7.1, 7.2** and **7.4** – Fractals and L-Systems, **Appendix B.3.1** – Production Grammars
- Lecture notes
  - Chapter 1: What is Life?
  - Chapter 2: The logical Mechanisms of Life
  - Chapter 3: Formalizing and Modeling the World
    - posted online @ casci.binghamton.edu/academics/i-bic



- Papers and other materials
  - Optional
    - Wigner, E.P. [1960], "The unreasonable effectiveness of mathematics in the natural sciences". *Comm. Pure Appl. Math.*, **13**: 1-14.
    - Flake's [1998], *The Computational Beauty of Life*. MIT Press.
      - Chapter **1** – Introduction
      - Chapters **5, 6** (7-9) – Self-similarity, fractals, L-Systems