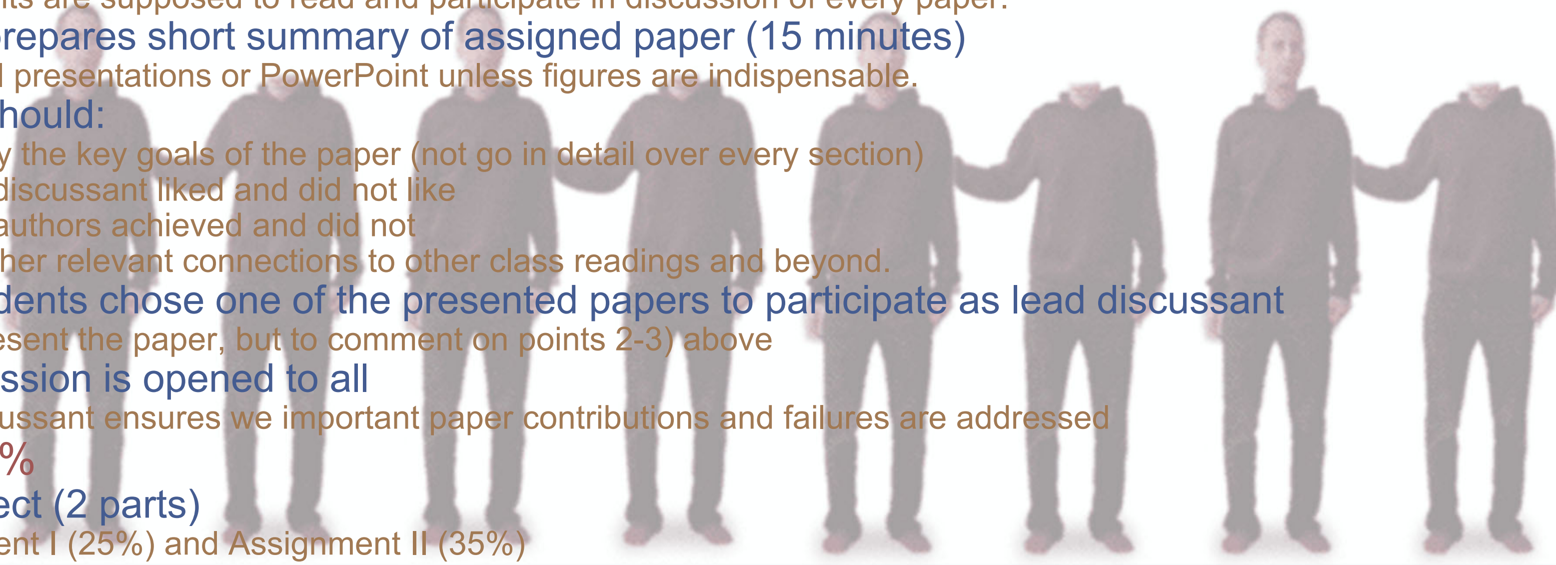
lecture 11: general systems theory

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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next readings (check brightspace)

- 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 2: Systems Science
  - Discussion Set 4 (Group 4): October 22nd
    - 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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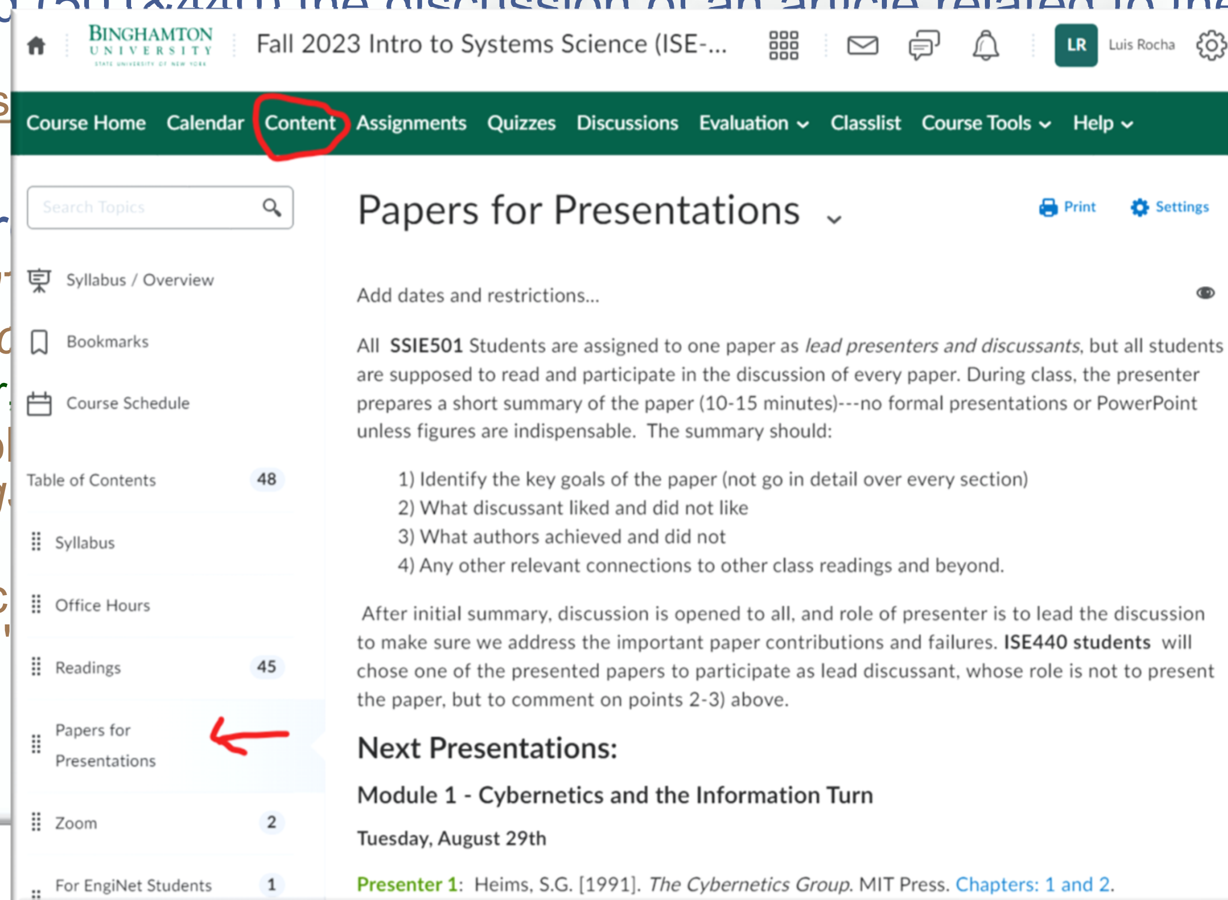
more upcoming readings (check brightspace)

- 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 3: Module 3 - The Organization of Complex Systems
  - Discussion Set 5 (Group 5)
    - Simon, H.A. [1962]. "The Architecture of Complexity". *Proceedings of the American Philosophical Society*, **106**: pp. 467-482.
      - Also available in Klir, G.J. [2001]. Facets of systems Science. Springer, pp: 541-559.
    - Golan, Amos, and John Harte. "Information theory: A foundation for complexity science." *Proceedings of the National Academy of Sciences* **119**.33 (2022): e2119089119.
    - James, R., and Crutchfield, J. (2017). "Multivariate Dependence beyond Shannon Information". *Entropy*, **19**(10), 531
  - See brightspace

more upcoming readings (check brightspace)

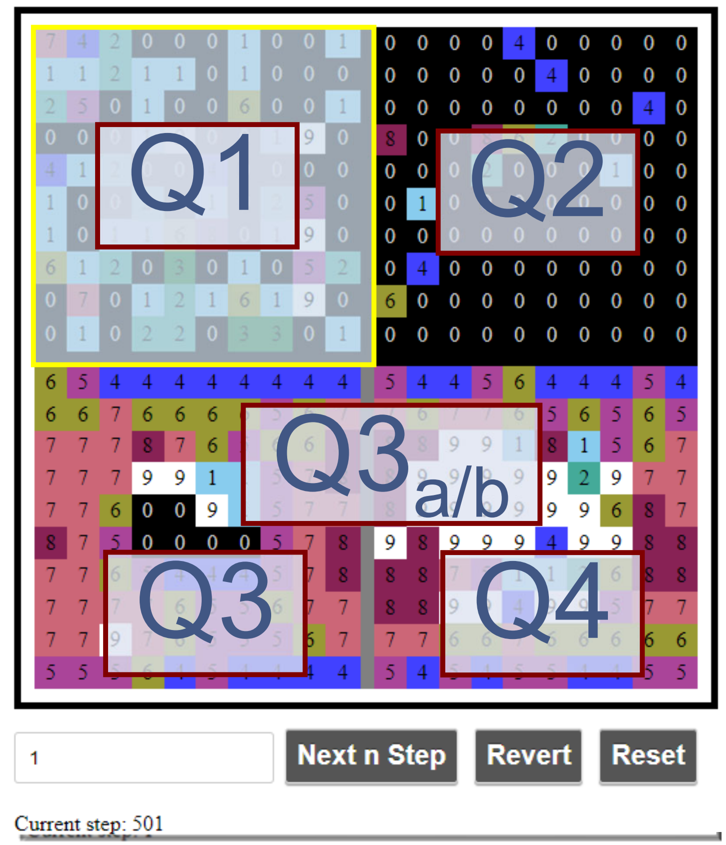
- Paper Presentation: 20%
  - Present (501) and lead (501&440) the discussion of an article related to the class materials
    - Enginet students post/s
- Module 3: Module 3 -
  - Discussion Set 5 (Gr
    - Simon, H.A. [1962]. " *American Philosophic*
      - Also available in Klir
    - Golan, Amos, and Jo science." *Proceeding* e2119089119.
    - James, R., and Crutc Shannon Information'
  - See brightspace



The Black Box II: Due: **November 22nd, 2024**

Herbert Simon: Law discovery means only finding **pattern** in the data; whether the pattern will continue to hold for new data that are observed subsequently will be decided in the course of **testing the law**, not discovering it. The **discovery process** runs from particular facts to general laws that are somehow induced from them; the **process of testing** discoveries runs from the laws to predictions of particular facts from them [...] To explain why the patterns we extract from observations frequently lead to correct predictions (when they do) requires us to face again the problem of **induction**, and perhaps to make some hypothesis about the uniformity of nature. But that hypothesis is neither required for, nor relevant to, the theory of discovery processes. […] By separating the question of pattern detection from the question of prediction, we can construct a **true normative theory of discovery**-a logic of discovery.

- Focus on uncovering quadrants
  - using data collection, descriptive patterns & statistics, and induction.
- Propose a formal model or algorithm of what each quadrant is doing.
  - Analyze, using deduction, the behavior of this algorithm.
- Maximum 20 pages!!!
  - 4 per quadrant + 4
  - Supporting information in separate file



What is it!!??

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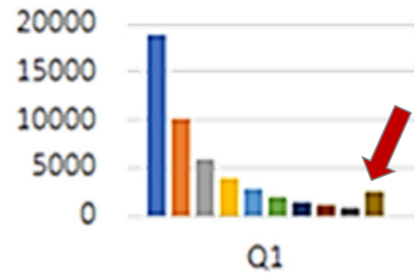
Questions and suggestions

- Remember "published" facts
  - Statistical behavior in Q1
  - Odd/Even behavior in Q2
  - Different regions, transition sequence, complexity in Q3/4
- Collect or request data (cite)
- Are there quadrant dependencies?
- Focus on smaller grid (mask) subsets?
- Think of neighborhoods and boundary conditions
- **Move from descriptive to mechanistic models**
- Induction and deduction
  - Data and reasoning
  - Given a model, are things you have never seen possible?

$$state(cell(i,j))_{t+1} = ?_t \otimes ?.....$$

Q1



0>1>2>3>4>5>6>7>8 >? 9

9s seem to have a slight advantage in prevalence ?

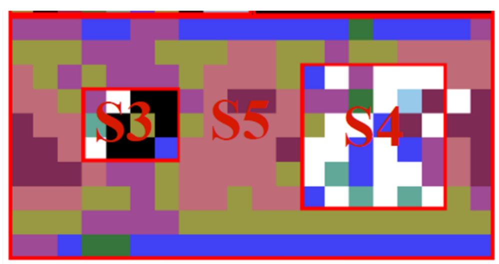
Q2

1. $0 \rightarrow 0$
2. $\{5\} \rightarrow \{0, 5\}$
3. $\{2, 4, 6, 8\} \rightarrow \{0, 2, 4, 6, 8\}$
4. $\{1, 3, 7, 9\} \rightarrow \{0, 1, 2, 3, 4, 5, 6, 7, 8, 9\}$

Q3 Q4

Outer S5 region model

Rug Rule



Are inner regions the same?

Cell heterogeneity…

Markov chain models likely insufficient

?

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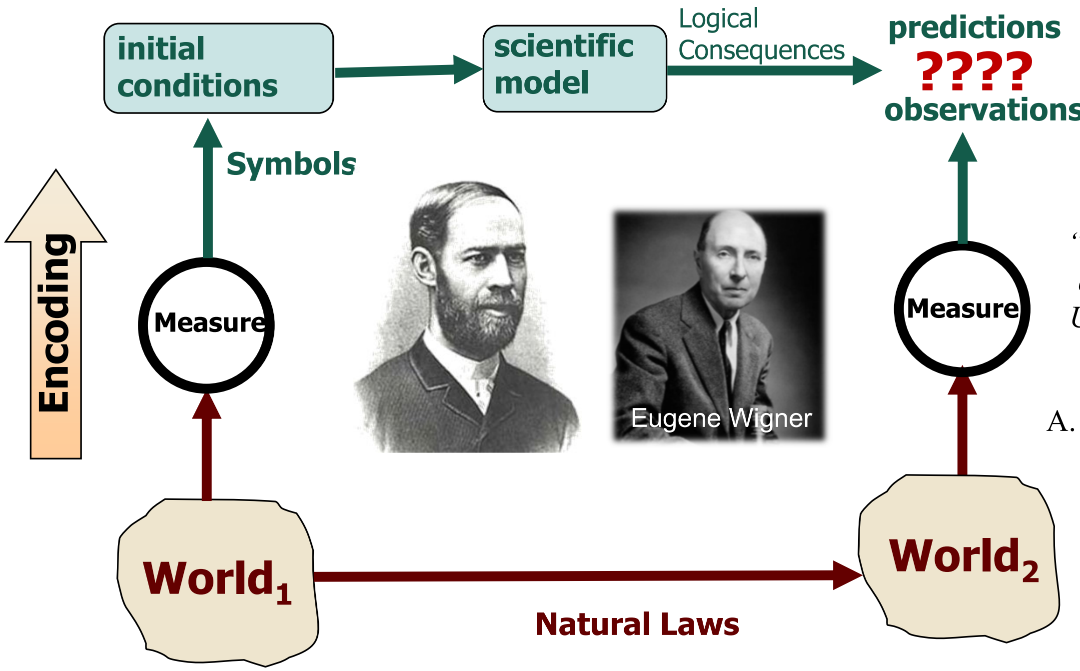
Hertzian scientific modeling paradigm



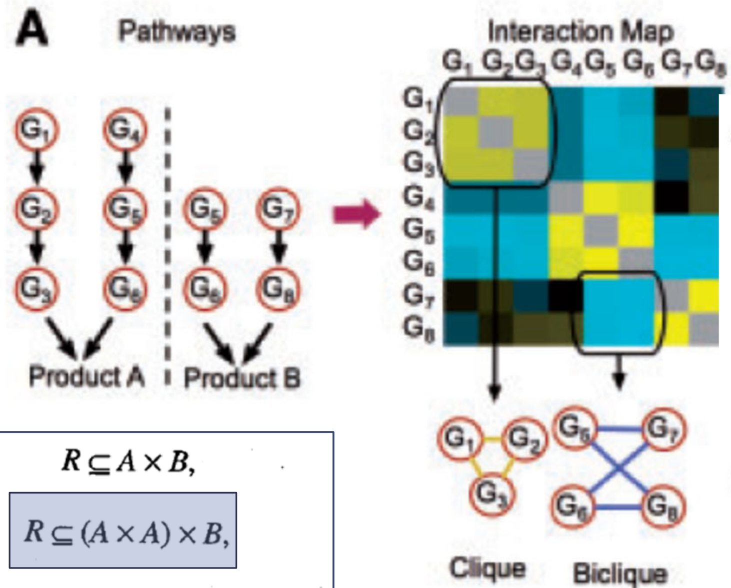
*“**Every empirical law has the disquieting quality that one does not know its limitations**.” E. Wigner [1957] in “The Unreasonable Effectiveness of Mathematics in the Natural Sciences”*

A. Rosenblueth and N. Wiener [1945] “The role of models in science.” *Philosophy of Science*. **12**(4): 316-321.”

C. Shalizi [2024] “Opening a closed box.” In: *Foundational Papers in Complexity Science, D.C.* Krakauer (Ed). pp. 149–169

“The most direct and in a sense the most important problem which our conscious knowledge of nature should enable us to solve is the ***anticipation of future events***, so that we may arrange our present affairs in accordance with such anticipation”. (Hertz, 1894)

From genetic interaction maps (in yeast)



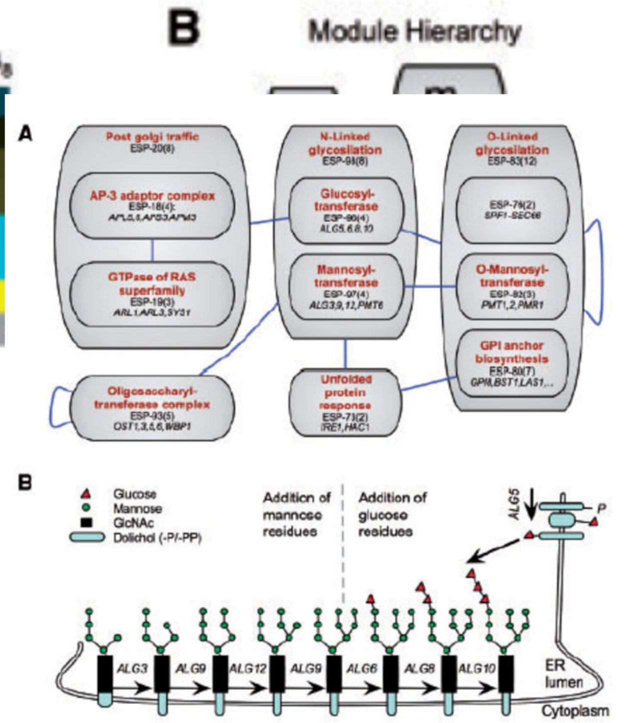
$$R \subseteq A \times B,$$

$$\boxed{R \subseteq (A \times A) \times B,}$$

$$R \subseteq (A \times B) \times (A \times B),$$

$$R \subseteq (A \times A \times A) \times B,$$

$$R \subseteq (A \times A \times A) \times (B \times B),$$



Jaimovich, Aet al. 2010. Modularity and directionality in genetic interaction maps. *Bioinformatics* **26**, no. 12 (June): i228-i236.

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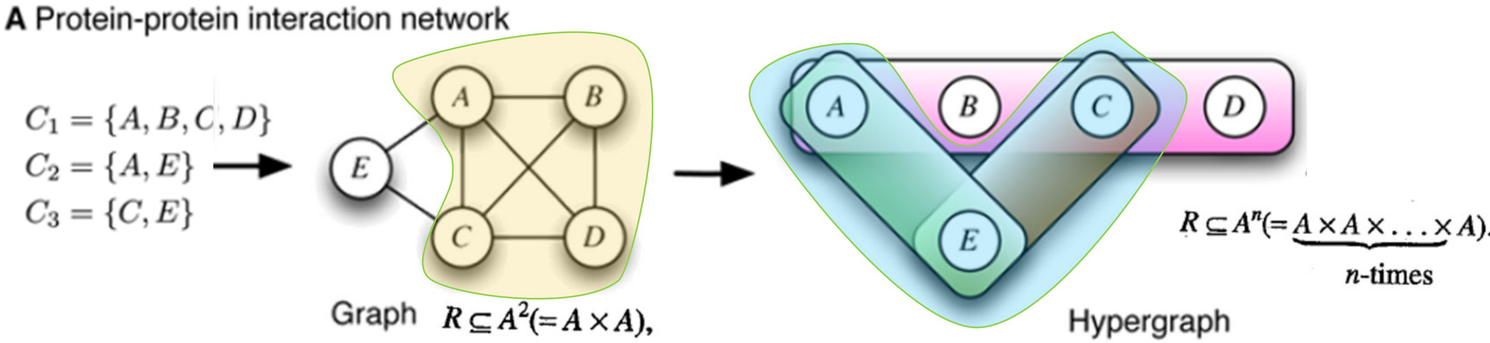
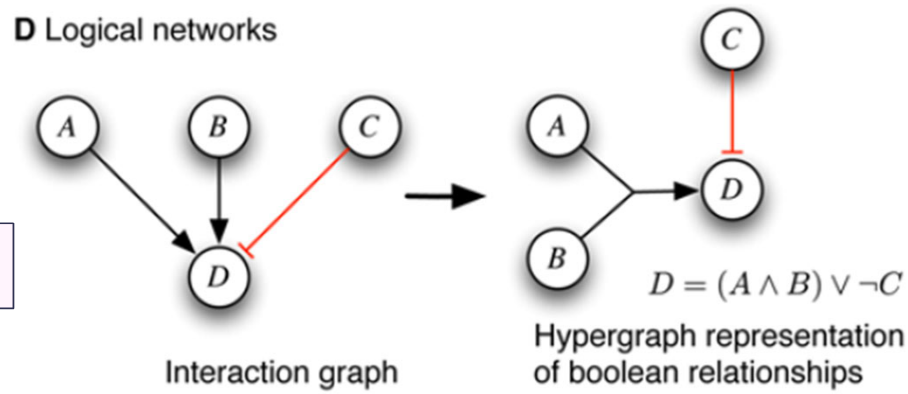
lead to different conclusions about underlying multivariate system



Max k-core:
$\{A,B,C,D\}, k = 3$

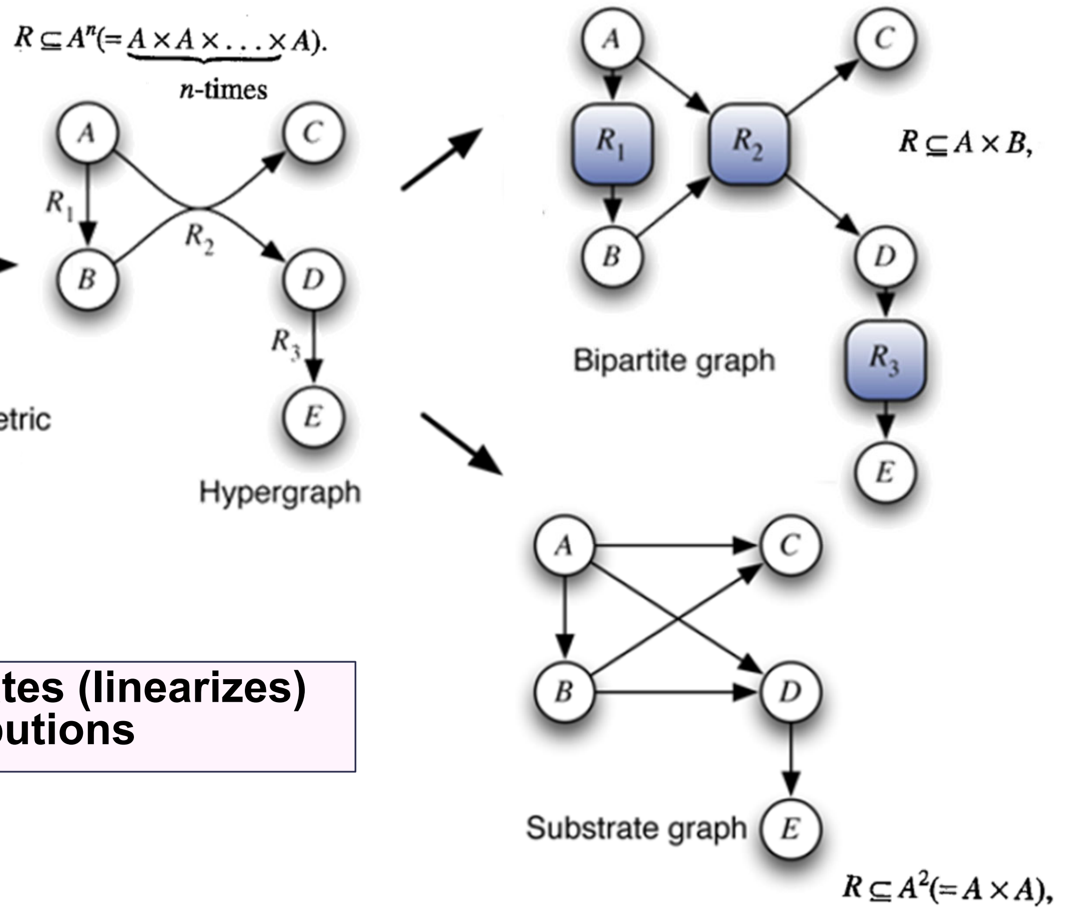
Max k-core:
$\{A,C,E\}, k = 2$



Separates (linearizes) contributions

Klamt S, Haus U-U, Theis F. [2010]. "Hypergraphs and cellular networks."*PLoS computational biology 5*(5): e1000385.

lead to different conclusions about underlying multivariate system



$$
\begin{array}{c|c}
 & \begin{array}{ccc} R_1 & R_2 & R_3 \end{array} \\
\begin{array}{c} A \\ B \\ C \\ D \\ E \end{array} & \begin{pmatrix} -1 & -1 & 0 \\ 1 & -1 & 0 \\ 0 & 1 & 0 \\ 0 & 1 & -1 \\ 0 & 0 & 1 \end{pmatrix}
\end{array}
$$

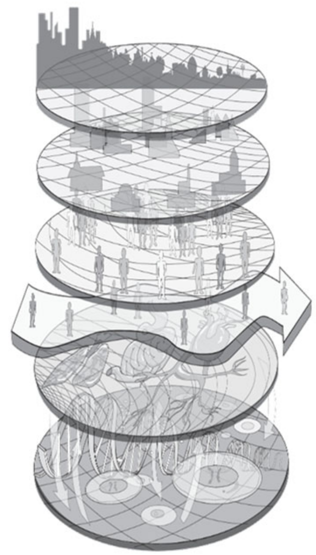
Separates (linearizes) contributions

Klamt S, Haus U-U, Theis F. [2010]. "Hypergraphs and cellular networks."*PLoS computational biology 5*(5): e1000385.

general-purpose study of “systems” properties of nature, technology, and society

systems thinking

- Traditional disciplines
  - defined by specific discernable levels of human experience in nature and society
    - Psychology, Sociology, Political Science, Economics, Physics, Chemistry, Biology, etc
- CNS, systems/computational thinking
  - General-purpose tools and universal laws
    - Search for **general principles** of **organization**
    - Produce machines and tools for all sciences
  - Disciplines are orthogonal to traditional disciplines
    - machine learning, network science, data science & analytics, dynamical systems theory, operations research, etc.
- 2-dimensional science
  - traditional disciplines focus on experimental and observational methods for specific subject matter
  - disciplines of CNS focus on generality of their own methods to any type of data
  - Neither parallel disciplines nor general-purpose methods are sufficient to achieve ***interdisciplinarity***
    - Team culture is necessary
    - E.g. Systems biology, computational biology, computational social science, etc.



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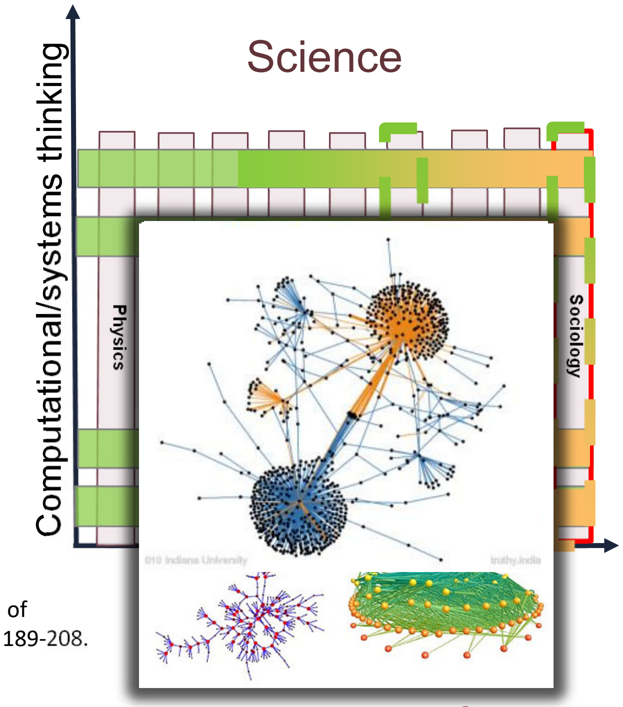

CNS NRT

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general-purpose study of “systems” properties of nature, technology, and society

complex networks & systems thinking

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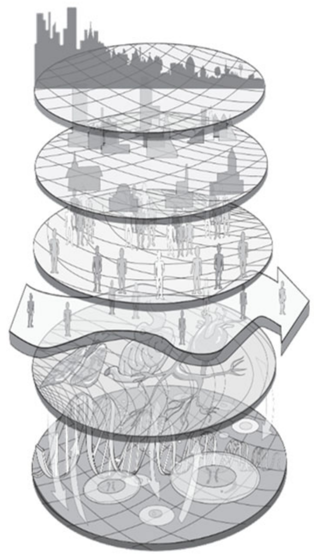

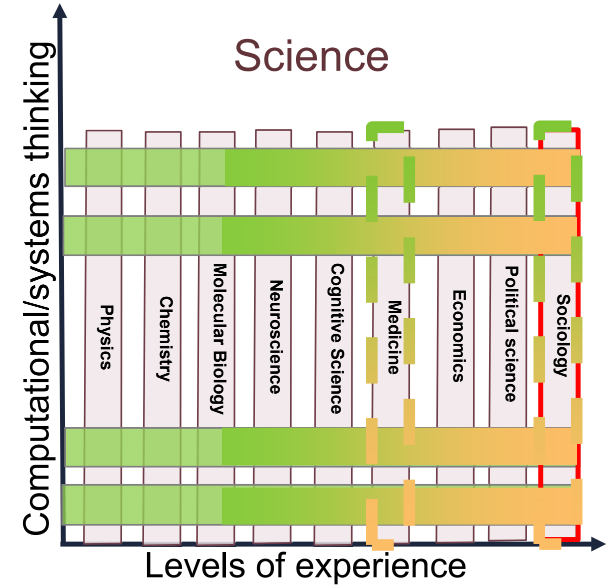

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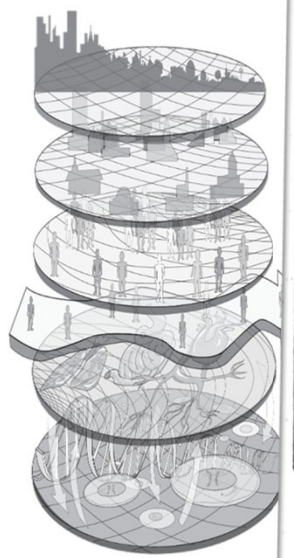

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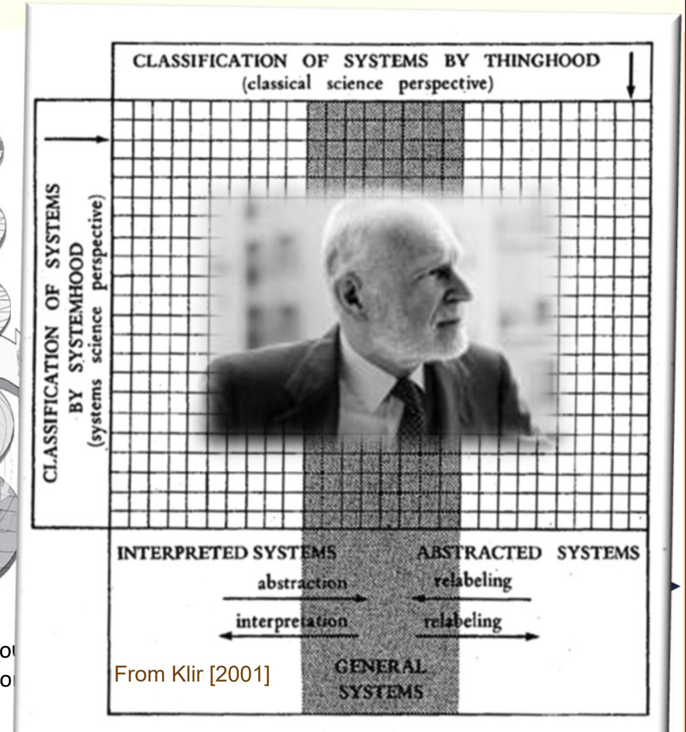

Figure 2.6. Two ways of classifying systems and the role of general systems.

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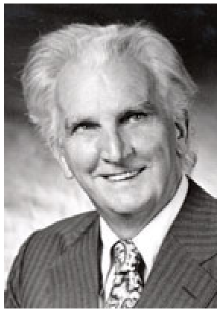
Models of organized complexity

- Systemhood properties
  - Search for a language of *generalized circuits*
  - Isomorphisms of concepts, laws and models across fields
  - Minimize duplication of efforts across fields
  - Unity of science
- Not mathematics
  - Kenneth Boulding
    - "in a sense, because mathematics contains all theories it contains none; it is the language of theory, but it does not give us the content"
    - "body of systematic theoretical construction which will discuss general relationships of the empirical World".
    - "somewhere between the specific that has no meaning and the general that has no content there must be, for each purpose an at each level of abstraction, an optimum degree of generality".
  - Empirical and problem-driven
- Other relevant areas
  - Mathematical theories of control and generalized circuits
  - Information theory
  - Optimal scheduling and resource allocation (operations research, ISE)
  - dynamical systems, chaos, AI, Alife, machine learning, network science, etc.

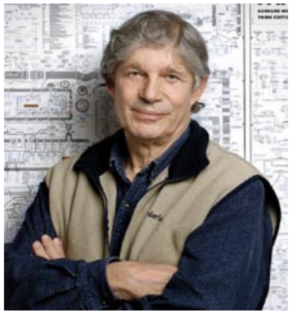
Ludwig
von Bertalanffy



Kenneth
Boulding

the theoretical biology component

- Systemhood properties of life
  - Search for a language of *generalized circuits*
  - Isomorphy of concepts, laws and models
  - Minimize duplication of efforts across fields
  - Unity of science
- Self-maintaining organization
  - **Dynamics** of regulation and development
    - **Networks** of simple interacting components
  - Dynamics of self-maintenance
    - Autopoiesis, auto-catalytic behavior, autonomy
- Evolutionary systems
  - Encoded production
  - Open-ended evolution
  - “leaky” systems


Stuart Kauffman


Ludwig von Bertalanffy


Howard Pattee


Francisco Varela

the theoretical biology component

- Systemhood properties of life
  - Search for a language of *generalized circuits*

  - "leaky" systems

Stuart Kauffman

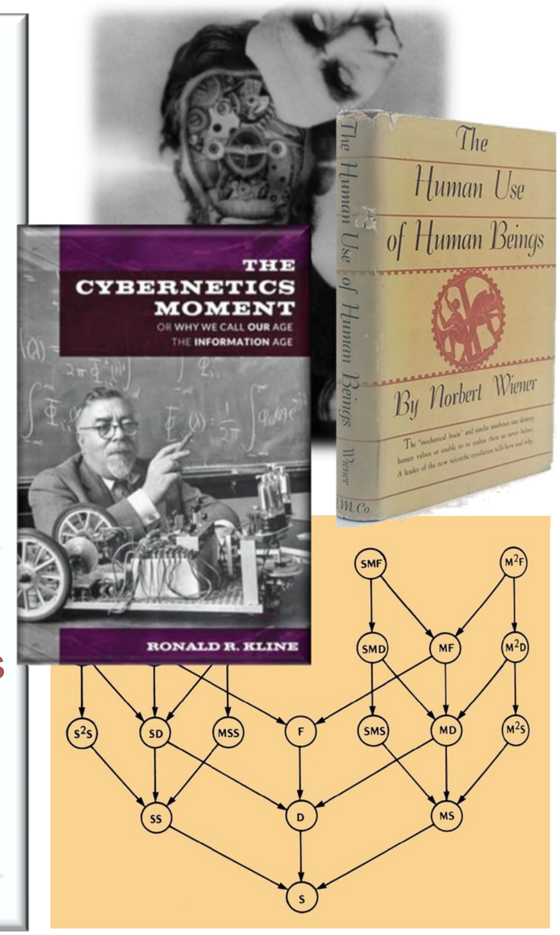
Ludwig
von Bertalanffy

Howard Pattee

Francisco Varela

The language lives on

- Learning and cognition as information transmission
  - Brain and mind as mechanism
- Computer as prevalent analogy/model for understanding life and cognition
- Feedback has come to mean information about the outcome of any process or activity
  - No word existed previously in English to convey that concept
- Interaction and organization everywhere
  - Attention shifted from individualism and cause & effect, to circular causation and social interaction
- “Programmed” behavior
- Society and organisms as (general) systems
- Wiener’s prediction of a second industrial revolution centered on communication, control, computation, information, and organization was correct
  - Abundance of technology and mass production of communication devices
    - Grew out of the ideas first reported by the cyberneticians
  - Many disciplines are an offspring of cybernetics



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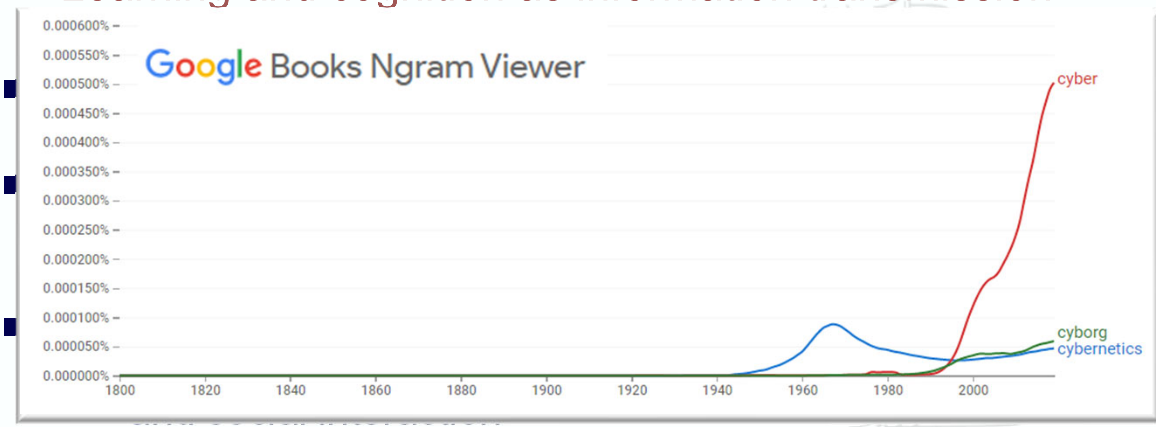
The language lives on

- Learning and cognition as information transmission



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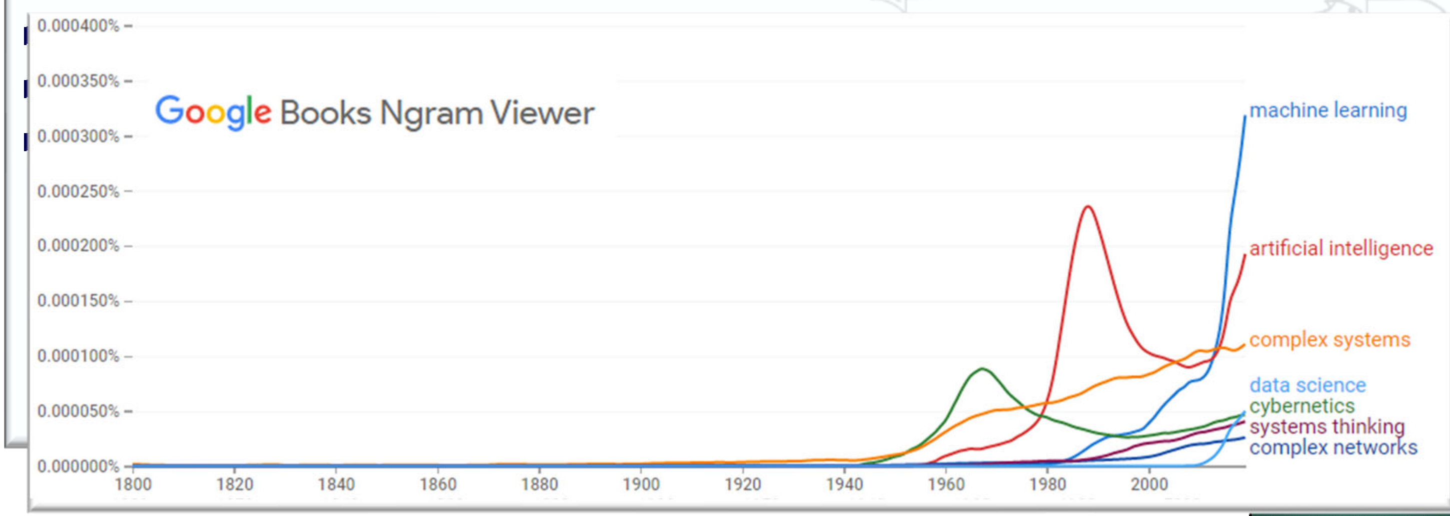
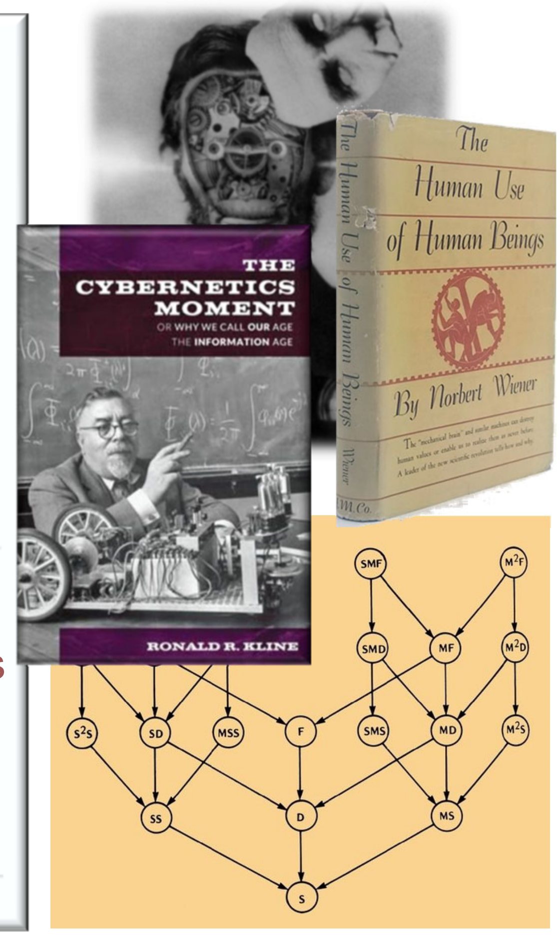
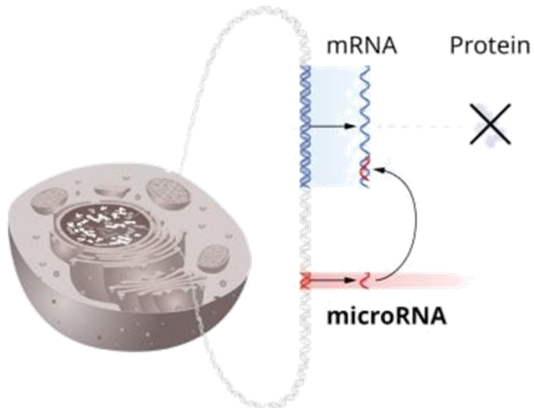
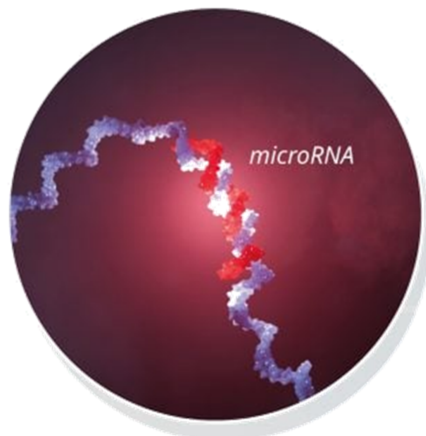
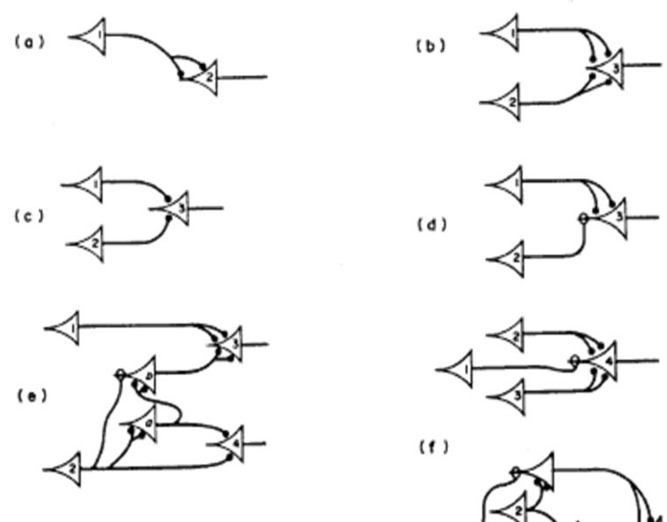


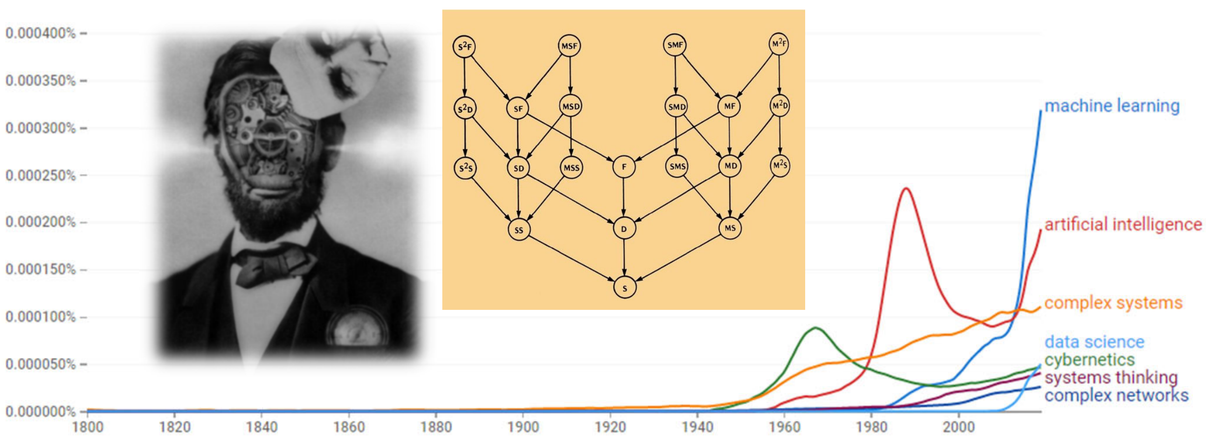


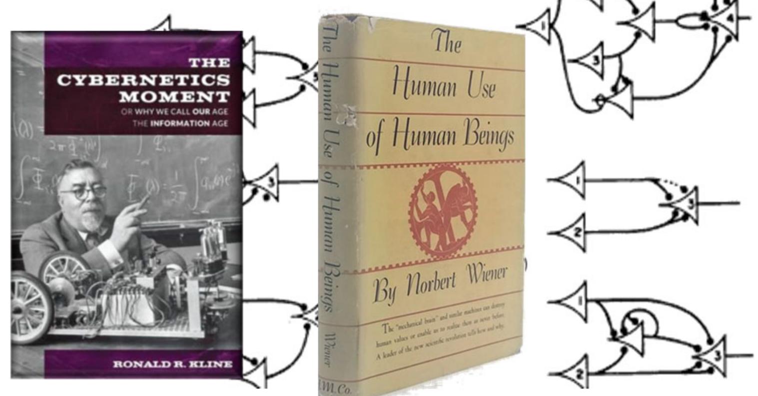
The concepts, tools, and interdisciplinary praxis lives on











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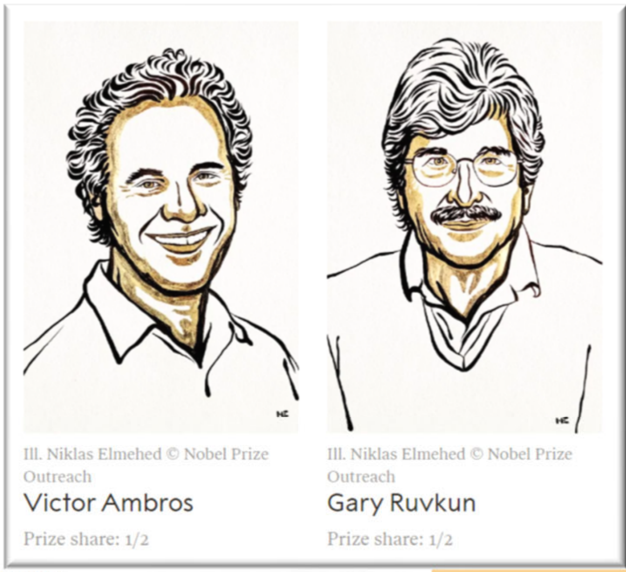
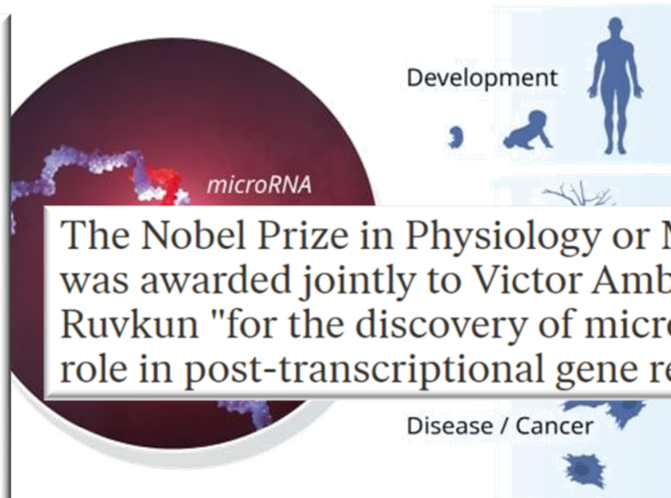
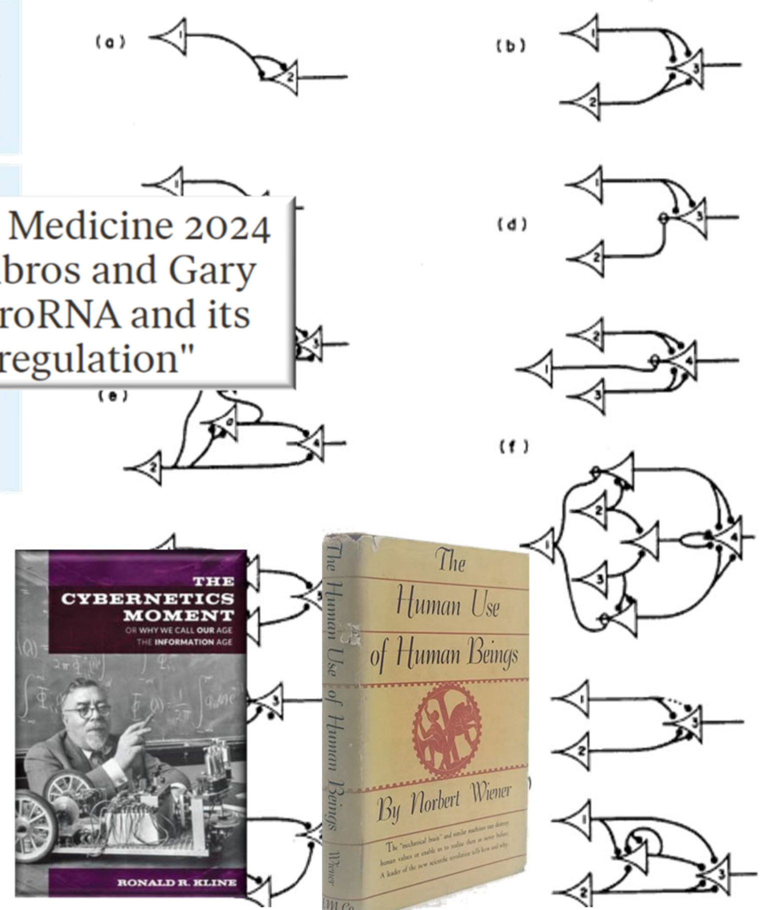
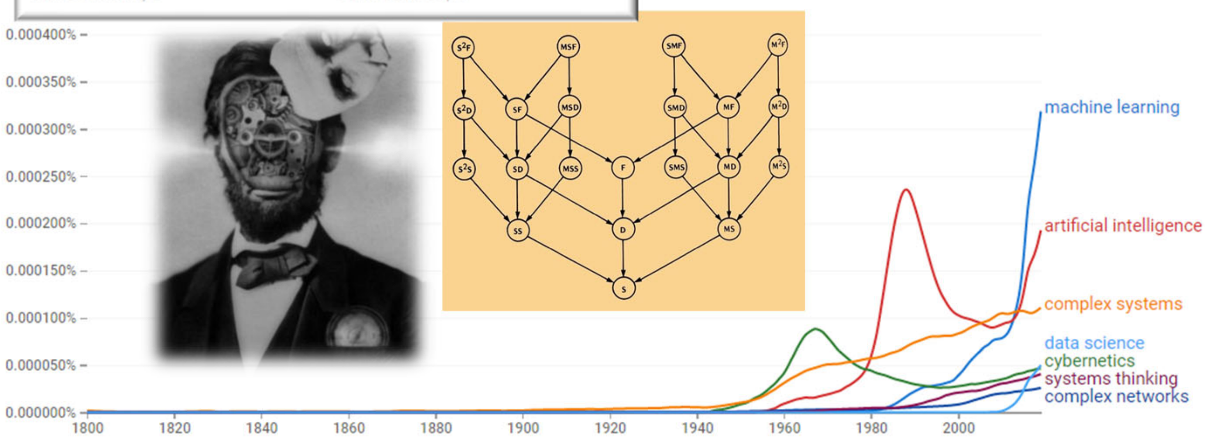




The Nobel Prize in Physiology or Medicine 2024 was awarded jointly to Victor Ambros and Gary Ruvkun "for the discovery of microRNA and its role in post-transcriptional gene regulation"





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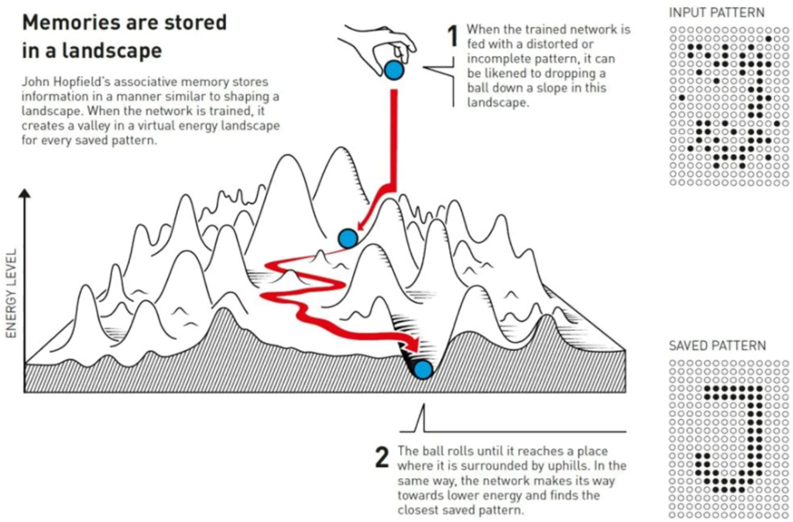

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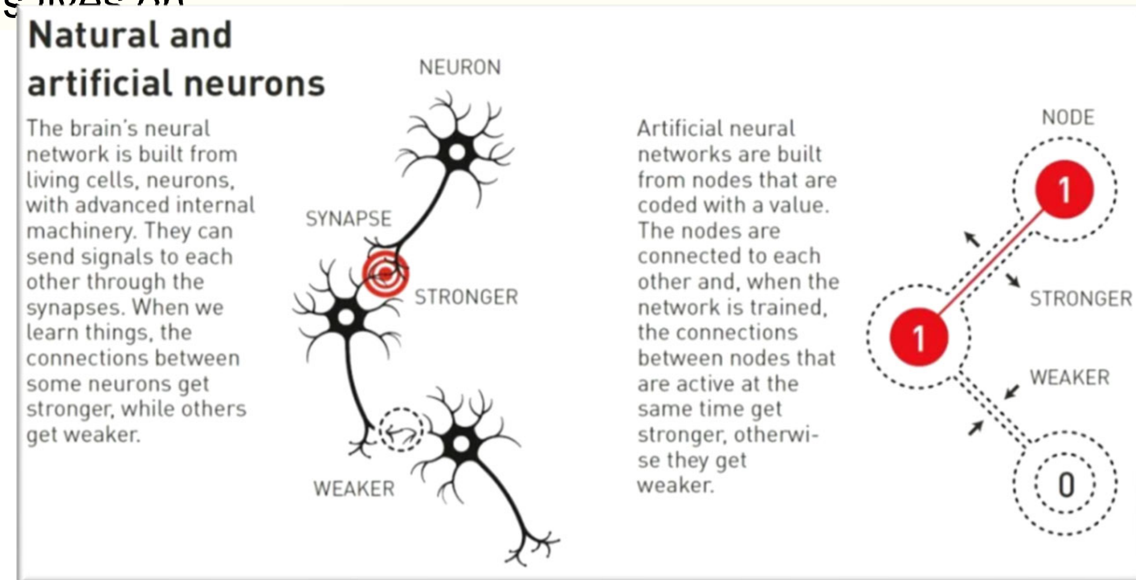

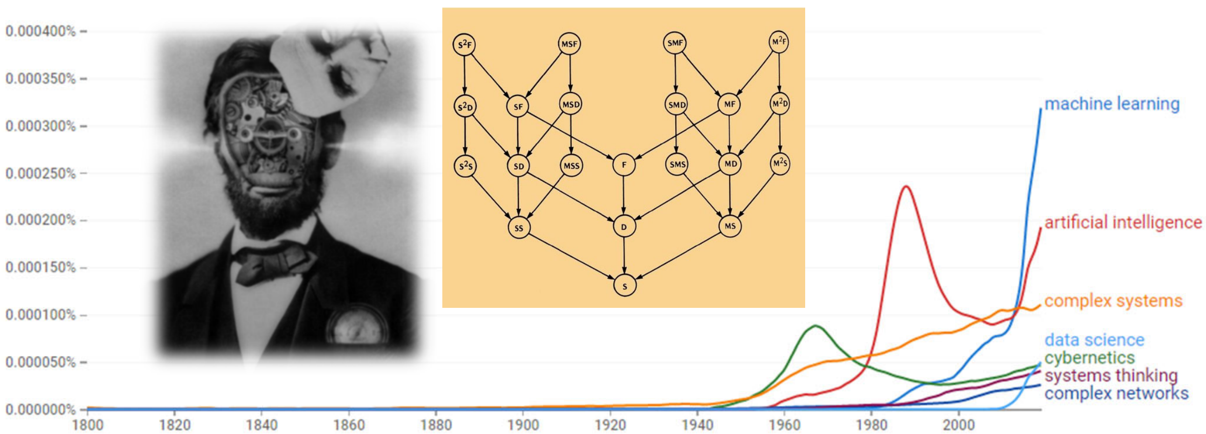

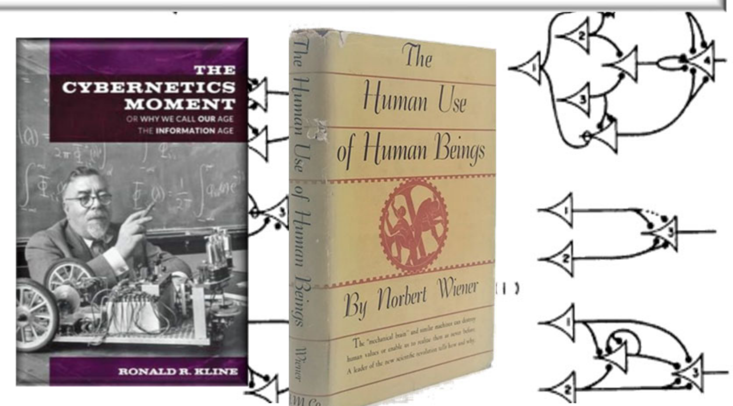

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The concepts, tools, and interdisciplinary praxis lives on

The Nobel Prize in Physics 2024

John Hopfield

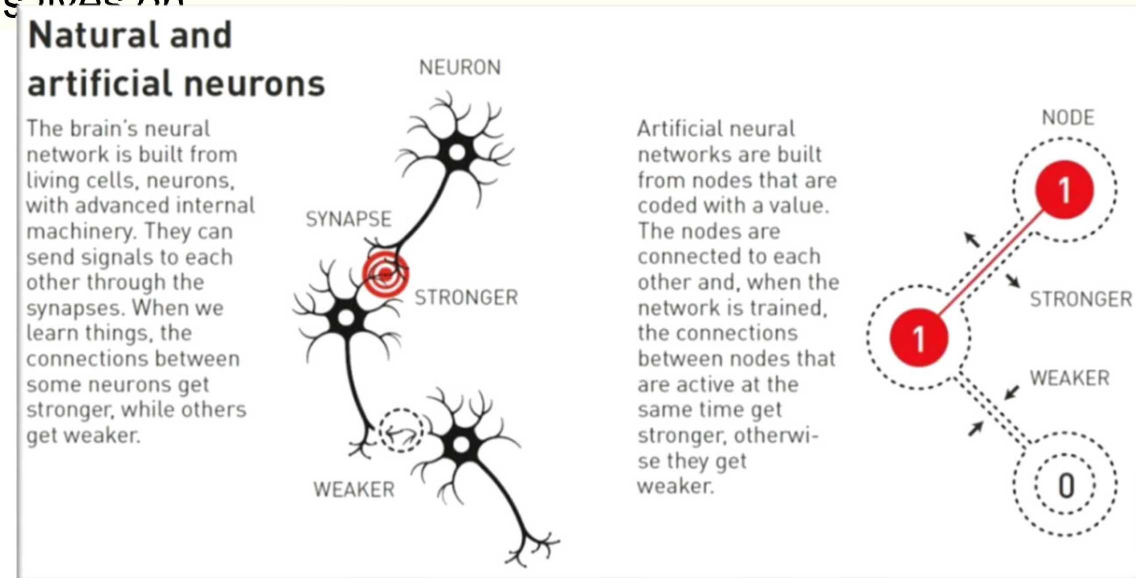
"for foundational discoveries and inventions that enable machine learning with artificial neural networks"

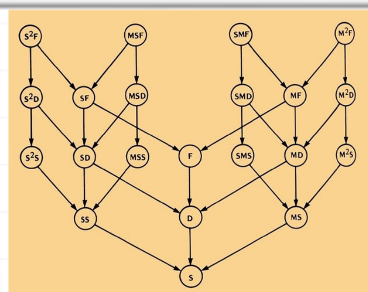
John Hopfield. Ill. Niklas Elmehed © Nobel Prize Outreach

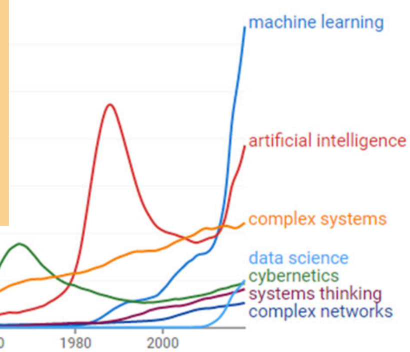
Geoffrey Hinton

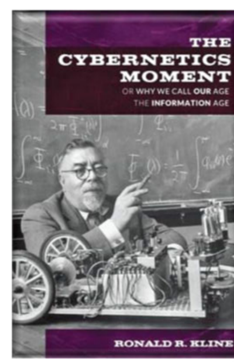
"for foundational discoveries and inventions that enable machine learning with artificial neural networks"

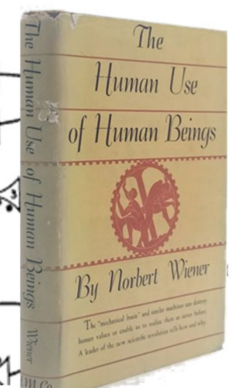
Geoffrey Hinton. Ill. Niklas Elmehed © Nobel Prize Outreach

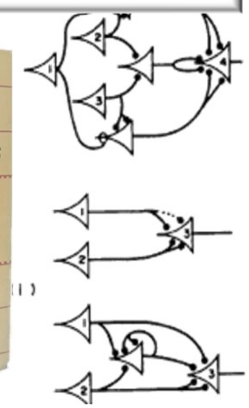












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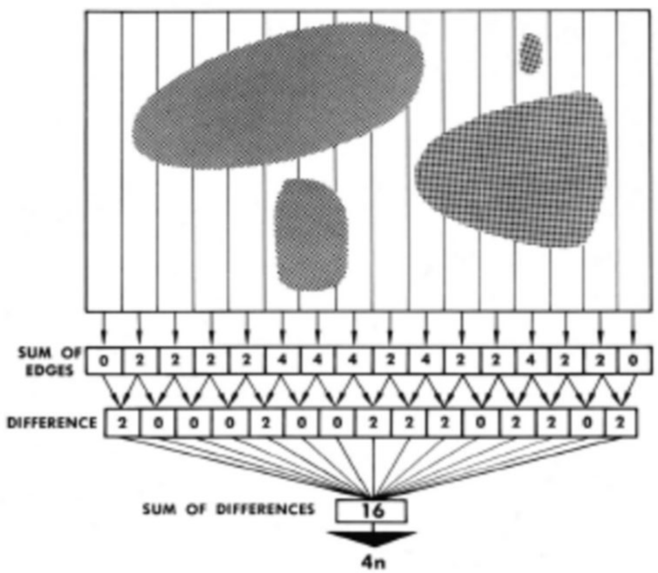
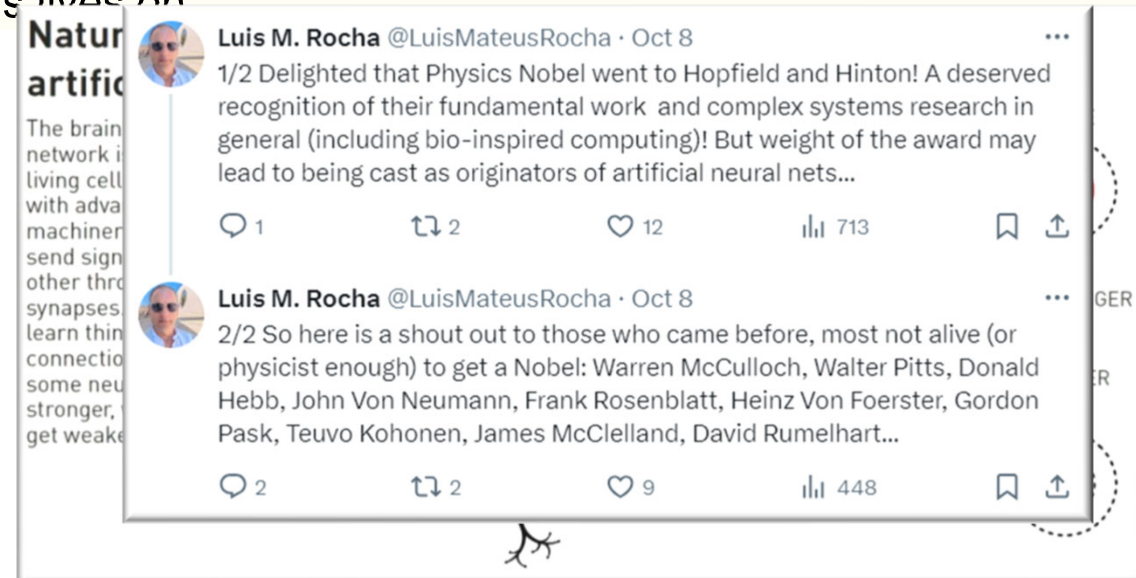
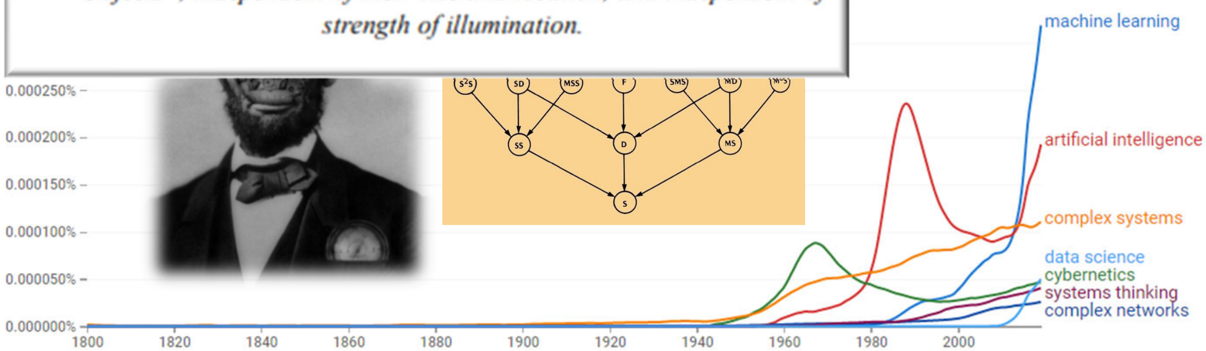
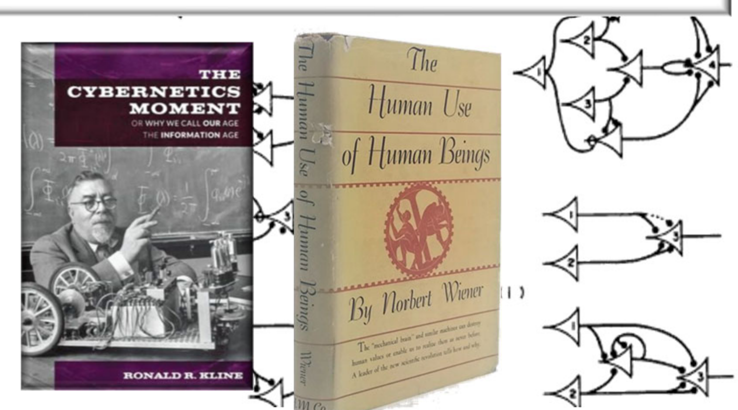
The concepts, tools, and interdisciplinary praxis lives on



16. *Two-dimensional network computing the invariants "N Convex Objects", independent of their size and location, and independent of strength of illumination.*







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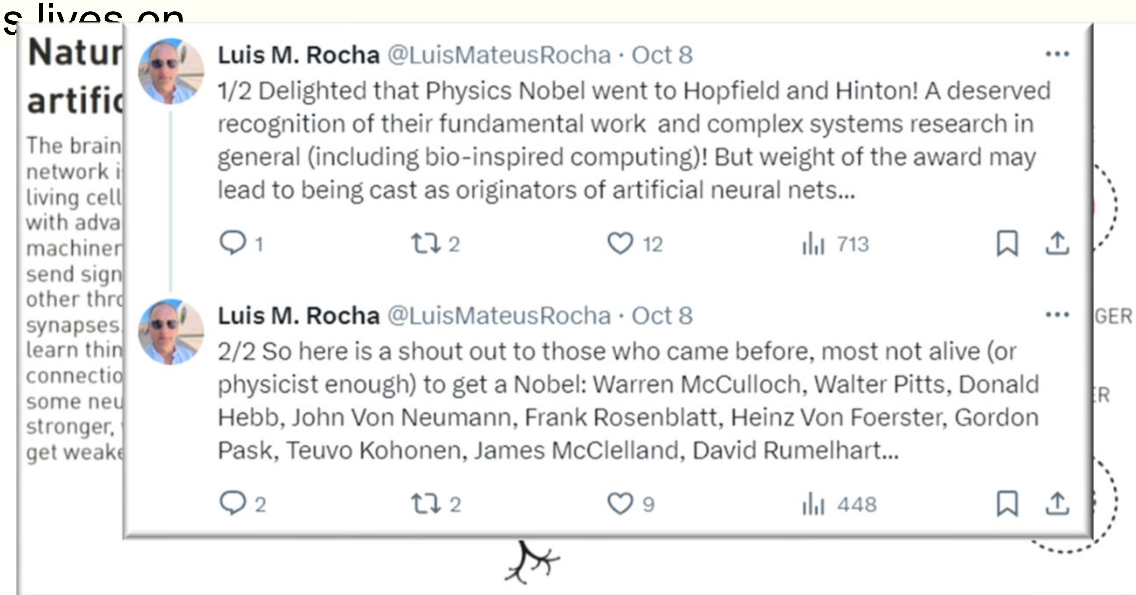
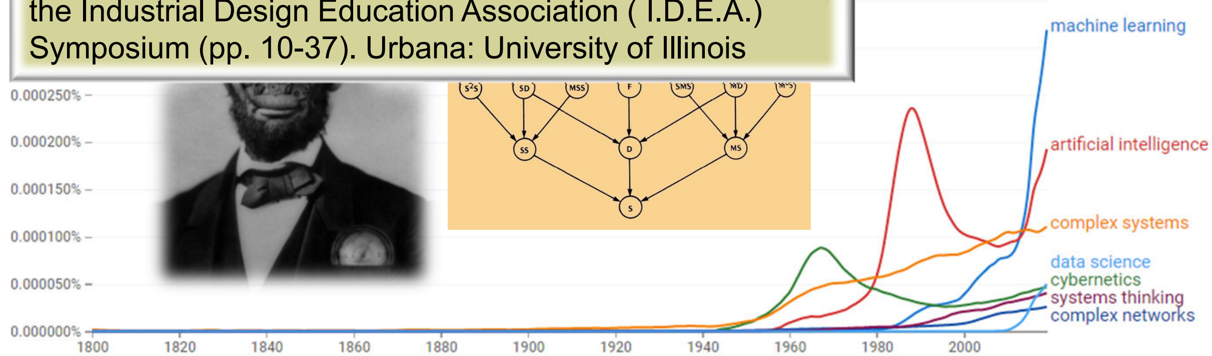
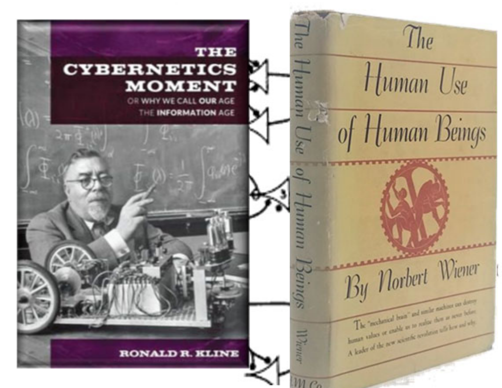
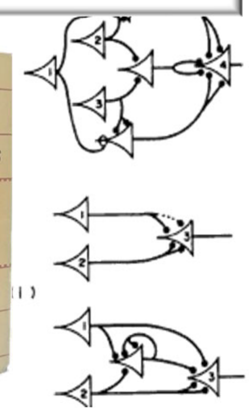
Weston, P. (2007). A walk through the forest. In A.Müller & K. H. Müller (Eds.), *An unfinished revolution? Heinz von Foerster and the Biological Computer Laboratory* | BCL 1958 –1976 (pp. 89-115).Vienna: echoraum.

von Foerster, H. (1962). Perception of form in biological and man-made systems. In E. J. Zagorski (Ed.), Trans. the Industrial Design Education Association (I.D.E.A.) Symposium (pp. 10-37). Urbana: University of Illinois









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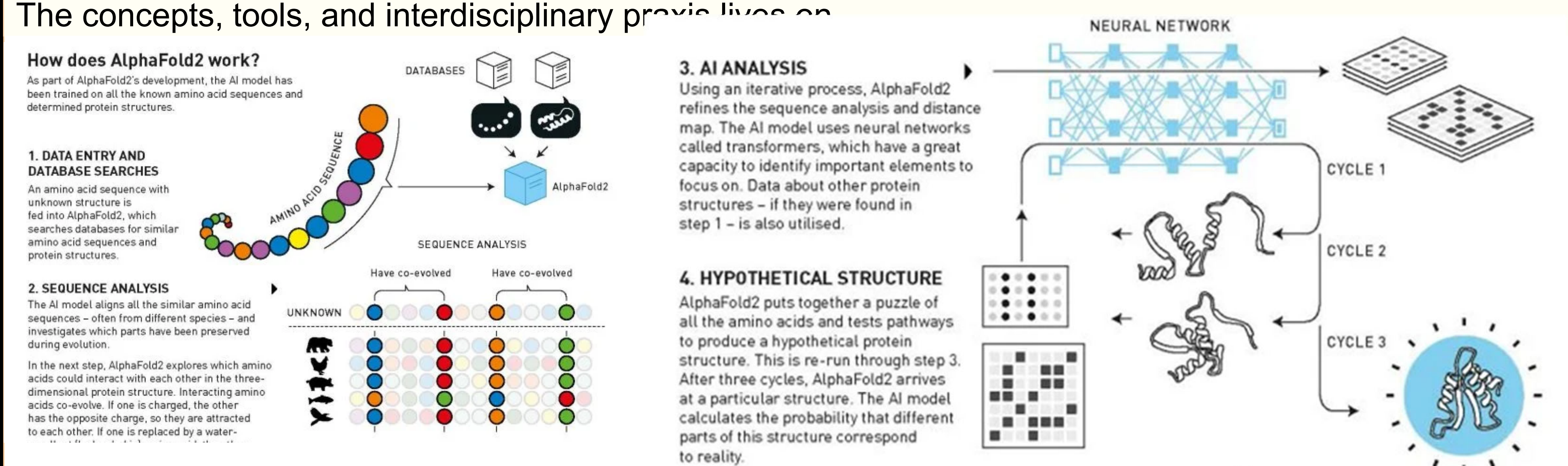

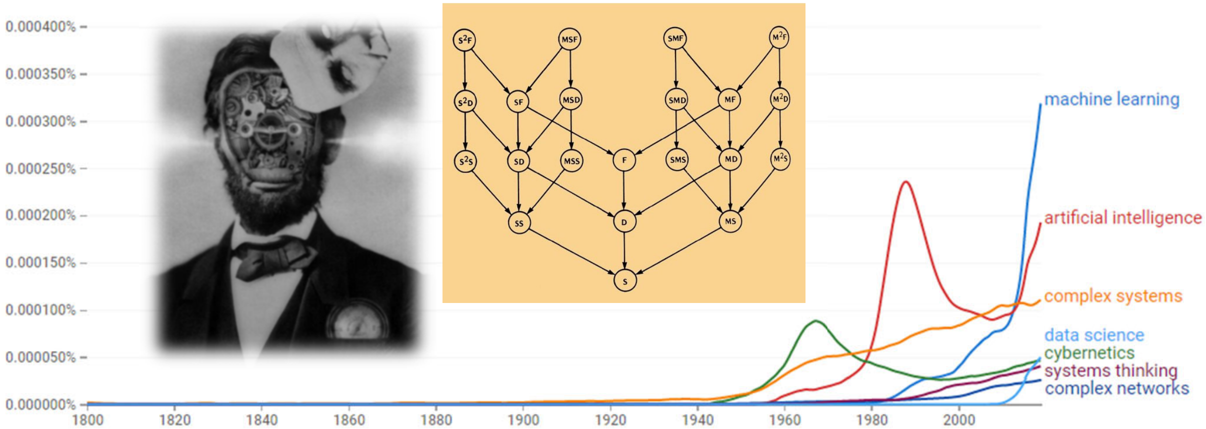

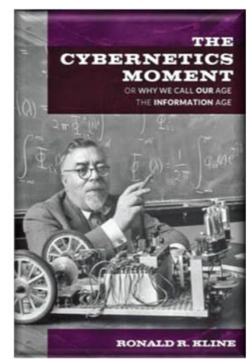

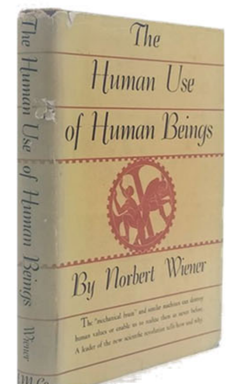

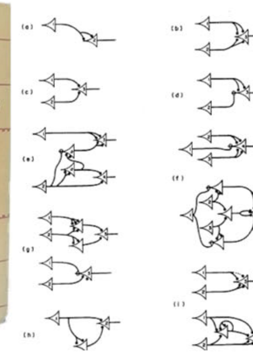

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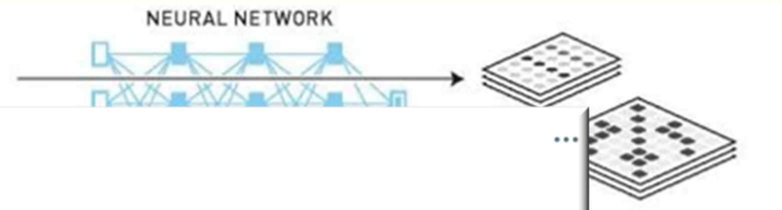

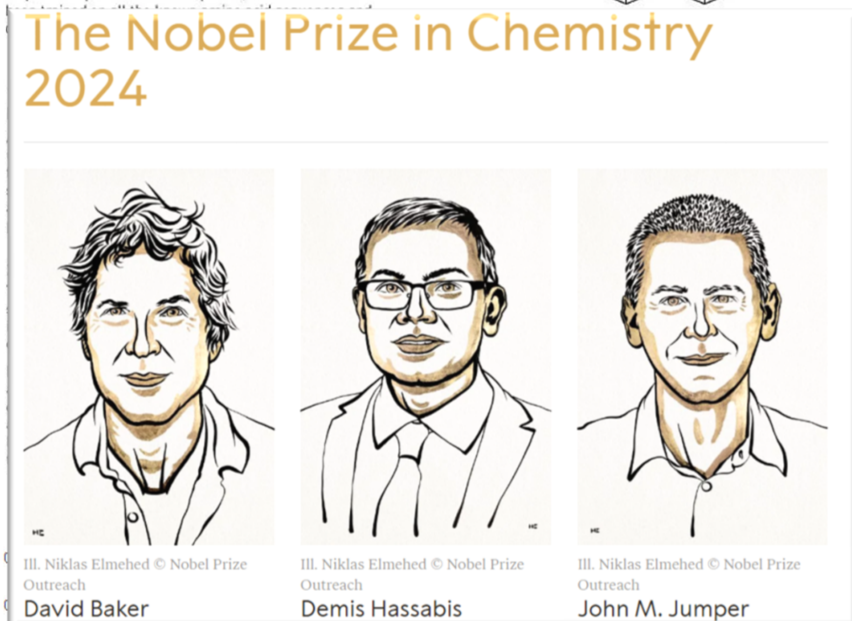

Luis M. Rocha
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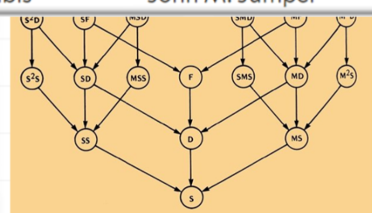
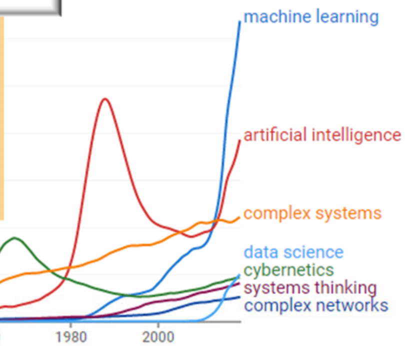
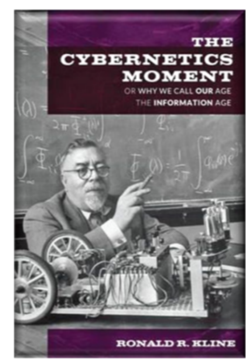
#NobelPrize in

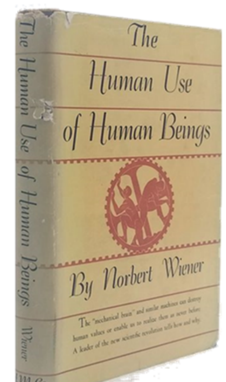
Physiology or Medicine: #Cybernetics (RNA silencing is biochemical information control)
Chemistry: #Cybernetics
Physics: #Cybernetics

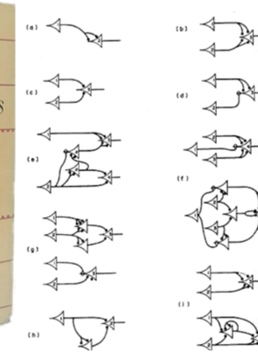
Wiener, Von Neumann, Turing, McCulloch, Pitts, Mead, Shannon, Von Foerster, Rosemblueth & co charted the interdisciplinary future











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readings

- Class Book
  - Klir, G.J. [2001]. *Facts of systems science*. Springer.
- Papers and other materials
  - Module 2: Systems Science
    - Discussion Set 4 (Group 4): October 17th
      - 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.

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