lecture 10: relations and general systems theory

evaluation

- Participation: 20%.
  - class discussion, everybody reads and discusses every paper
  - engagement in class, including online
- Paper Presentation and Discussion: 20%
  - All students are assigned to a Reading and Discussion Group
  - **SSIE501** students in group present and discuss papers
    - all students are supposed to read and participate in discussion of every paper.
    - *section 01 groups* present in class, *section 20 groups* present via zoom or send a video
  - Presenter group prepares short summary of assigned paper (15 minutes)
    - no formal presentations or PowerPoint unless figures are indispensable.
  - Summary should:
    - 1) Identify the key goals of the paper (not go in detail over every section)
    - 2) What discussant liked and did not like
    - 3) What authors achieved and did not
    - 4) Any other relevant connections to other class readings and beyond.
  - **ISE440** students in group participate as lead discussants
    - not to present the paper, but to comment on points 2-3) above
  - Class discussion is opened to all
    - lead discussant ensures important paper contributions and failures are addressed
  - Post presentation 1-2 page report uploaded to Brightspace
    - 1-4) plus 5) statement of individual contributions
- Black Box: 60%
  - Group Project (2 parts)
    - Assignment I (25%) and Assignment II (35%)

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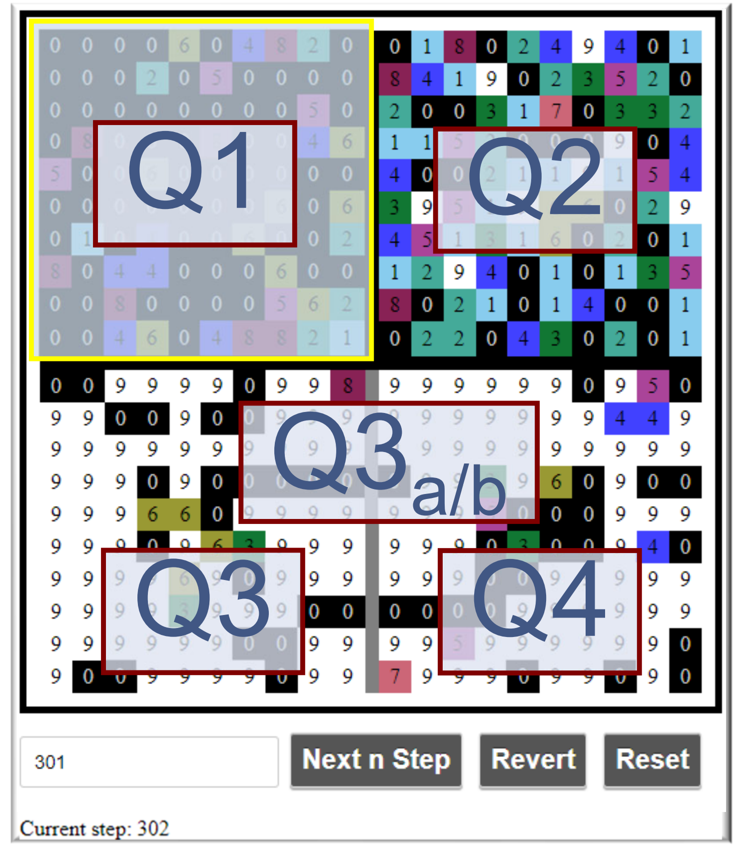
The Black Box: Due: October 6th, 2023

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.



What is it!!??

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)
- Thursday September 21st
  - Module 2: Systems Science
    - Reading and Discussion Group 3 (Enginet)
      - Sarah Donovan, Nicole Dates, et al:
        - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 2.
          - Optional:
          - Rosen, R. [1986]. "Some comments on systems and system theory". *Int. J. of General Systems*, **13**: 1-3. Available in: Klir, G.J. [2001]. *Facets of systems Science*. Springer. pp: 241-243.
          - Wigner, E.P. [1960], "The unreasonable effectiveness of mathematics in the natural sciences". Richard courant lecture in mathematical sciences delivered at New York University, May 11, 1959. *Comm. Pure Appl. Math*, **13**: 1-14.
        - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 3.
- 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
  - *section 01* presents in class, *section 20* (Enginet) posts videos on Brightspace (exceptions possible)
- October 3rd
  - Module 2: Systems Science
    - Reading and Discussion Group 4
      - 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.
- October 10/12th
  - Module 3 - The Organization of Complex Systems
    - Reading and Discussion Group 5 (Enginet)
      - 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.
- Future Modules
  - See brightspace

more upcoming readings (check brightspace)

- Paper Presentation: 20%
  - Present (501) and lead (501&44(materials
  - *section 01* presents in class, *section*
- October 3rd
  - Module 2: Systems Science
    - Reading and Discussion Group 4
      - Klir, G.J. [2001]. *Facets of systems Sc*
        - Optional: Klir, G.J. [2001]. *Facet*
      - Schuster, P. (2016). The end of Moore *Complexity*. **21**(S1): 6-9. DOI 10.1002/
      - Von Foerster, H., P. M. Mora and L. W 5.
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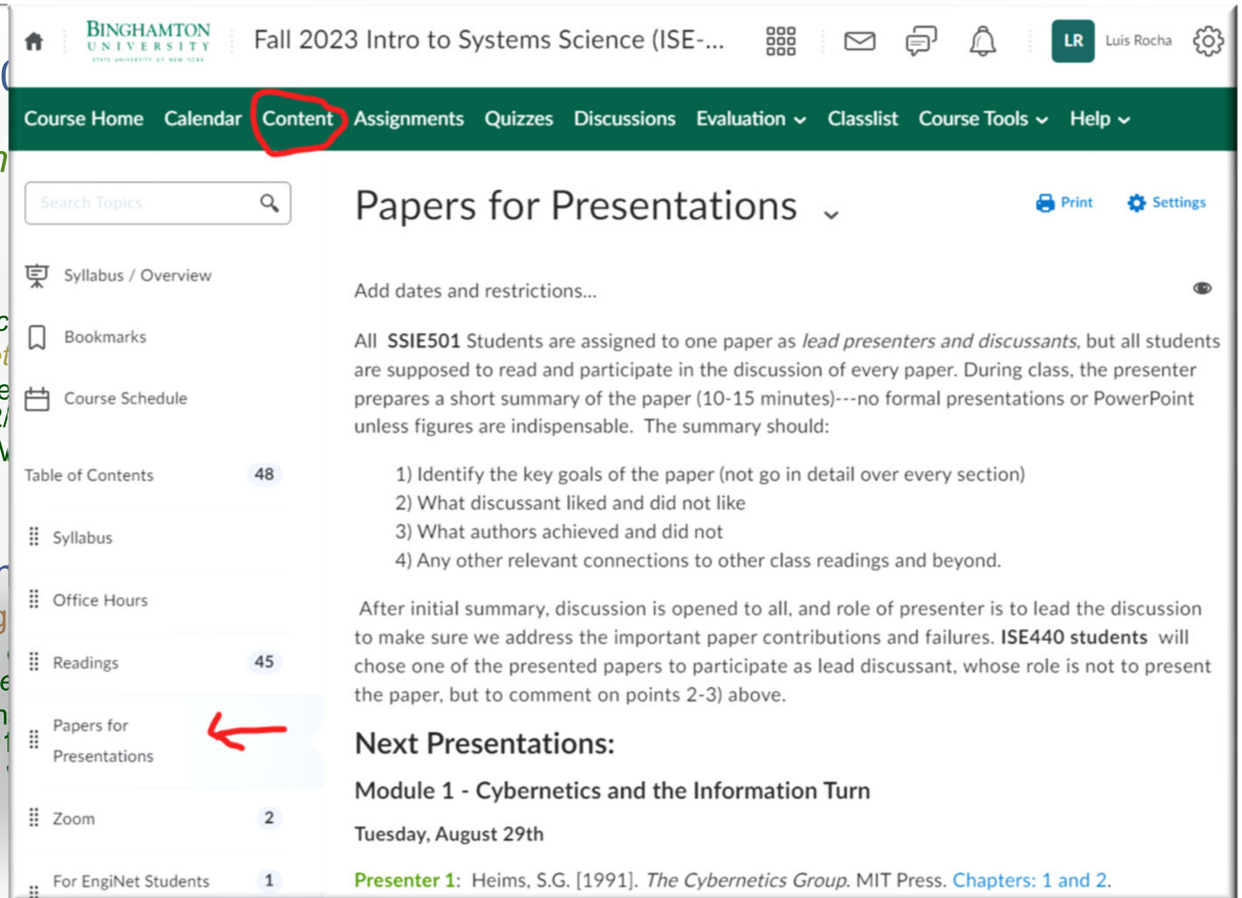
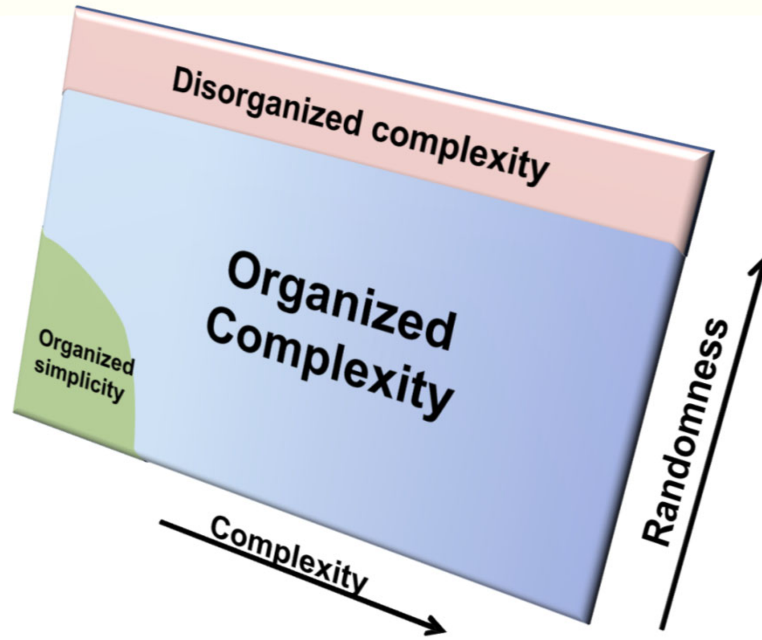
    - Reading and Discussion Group 5 (Eng
      - Simon, H.A. [1962]. "The Architecture Also available in Klir, G.J. [2001]. *Face*
      - Golan, Amos, and John Harte. "Inform *of Sciences* **119**.33 (2022): e21190891
      - James, R., and Crutchfield, J. (2017).
- Future Modules
  - See brightspace



from computational to systems thinking

- organized complexity
  - study of <u>organization</u>
    - whole is more than sum of parts
    - Organizational properties (“systemhood”)
  - Need for new mathematical and <u>computational tools</u>
    - Massive combinatorial searches
    - Problems that can only be tackled with computers
      - Computer as lab
  - Interdisciplinary and collaborative science
    - Thrives in problem-driven environments
      - Los Alamos, Santa Fe, all new computing centers.
- **<u>thinghood and systemhood</u>**
  - developing general-purpose computing further
    - Computational thinking and cybernetics
      - Some (all?) mechanisms and organizational principles are implementation-independent
      - Hardware vs software
  - **<u>Integration</u>** of empirical science with general systems
    - Interdisciplinarity coupled with computational modeling
  - Understanding structure and *function*
    - Of multi-level wholes
      - Systems biology, Evolutionary thinking, Systems thinking
    - **Emergence** (or collective behavior)
      - How do elements combine to form new unities?
      - **Micro- to macro-level behavior**



key roots

- Mathematics
- Computer Technology and Computational Thinking
- Systems Thinking
  - Cybernetics
    - Looking at mind, life, society with control, computation, information, networks
  - Functional equivalence
    - General principles and modeling
  - Organized Complexity
    - Study of organization
    - "Whole is more than some of parts", nonlinearity, interaction, communication
  - Interdisciplinary outlook
    - Not just math and computing, modeling requires understanding of focus domain
    - Bio-inspired mathematics and computing
    - Computing/Mechanism-inspired biology and social science

1965: Society for the Advancement of General Systems Theory

Kenneth Boulding

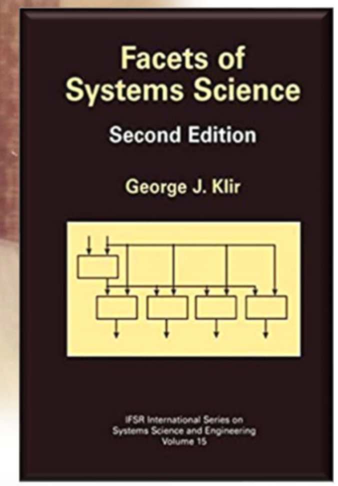
Ludwig von Bertalanffy

Ralph Gerard

Anatol Rapoport

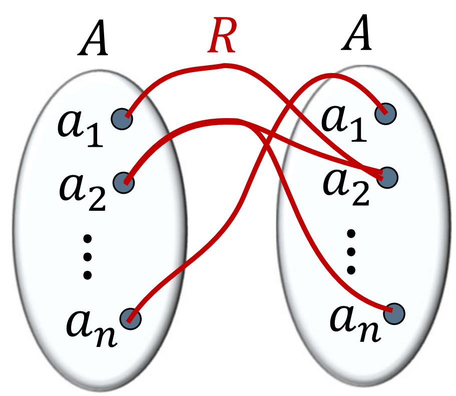
a science of organization across disciplines

- 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.)

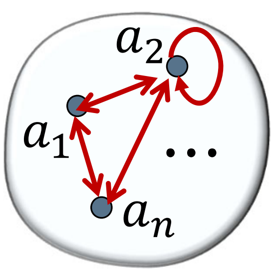


more formally: representation of multivariate of associations/interactions

- $S = (T, R)$
  - a (multivariate) system
- $T = \{A_1, A_2, \ldots, A_n\}$
  - A set (of sets) of things
    - *thinghood*
- Cartesian Product
  - Set of all possible associations of elements from each set
    - All n-tuples
  - $\{A_1 \times A_2 \times \ldots \times A_n\}$
- R: a relation (systemhood)
  - Subset of cartesian product on T.
    - Many relations R can be defined on the same T



$R \subseteq A^2 (= A \times A),$



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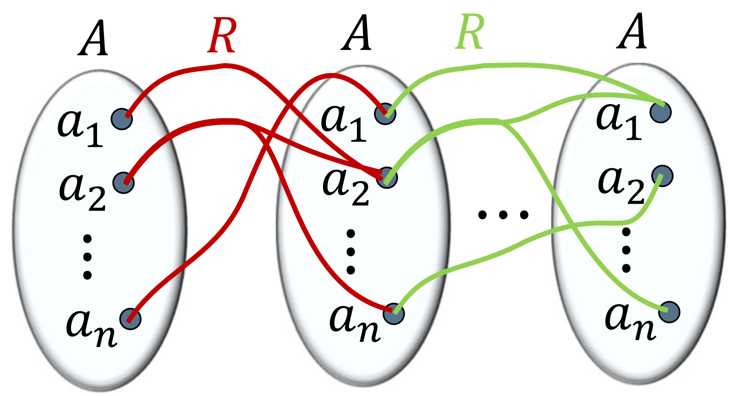

$R \subseteq A^2(=A \times A)$,

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....

$R \subseteq A^n(= \underbrace{A \times A \times \ldots \times A}_{n\text{-times}})$.

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

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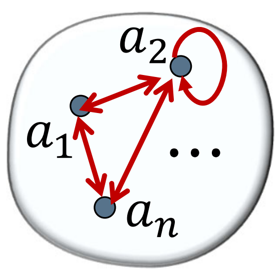
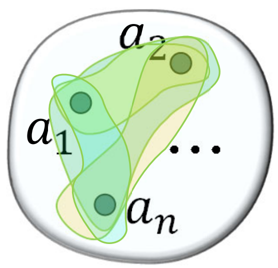
$R \subseteq (A \times A) \times (A \times A)$.

graph A



hypergraph A



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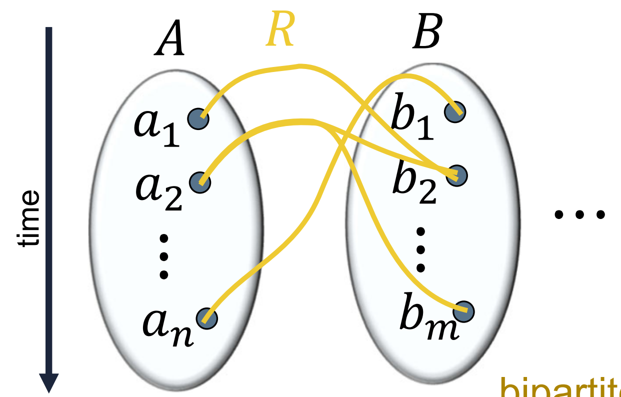

bipartite graph

$R \subseteq A^2 (= A \times A),$

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$\ldots\ldots\ldots\ldots\ldots\ldots$

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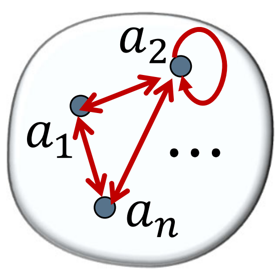
graph A



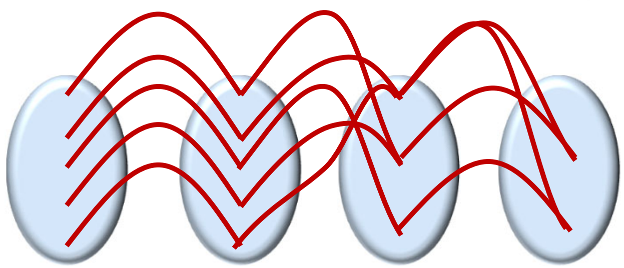
equivalence classes or multilayer network?

Table 2.1. Set of Students with Four Characteristics

Student	Grade	Major	Age	Full-time/ part-time
Alan	B	Biology	19	Full-time
Bob	C	Physics	19	Full-time
Cliff	C	Mathematics	20	Part-time
Debby	A	Mathematics	19	Full-time
George	A	Mathematics	19	Full-time
Jane	A	Business	21	Part-time
Lisa	B	Chemistry	21	Part-time
Mary	C	Biology	19	Full-time
Nancy	B	Biology	19	Full-time
Paul	B	Business	21	Part-time

Table 2.2. Equivalence Relation R_g Defined on the Set of Students Listed in Table 2.1 with Respect to Their Grades

R_g	A	B	C	D	G	J	L	M	N	P
A	1	0	0	0	0	0	1	0	1	1
B	0	1	1	0	0	0	0	1	0	0
C	0	1	1	0	0	0	0	1	0	0
D	0	0	0	1	1	1	0	0	0	0
G	0	0	0	1	1	1	0	0	0	0
J	0	0	0	1	1	1	0	0	0	0
L	1	0	0	0	0	0	1	0	1	1
M	0	1	1	0	0	0	0	1	0	0
N	1	0	0	0	0	0	1	0	1	1
P	1	0	0	0	0	0	1	0	1	1



$$R \subseteq A \times B \times C \times D$$

Note: same thinghood (set of students), but distinct systemhood or organization projected to a specific set (layer) as equivalence classes.

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equivalence classes or multilayer network?

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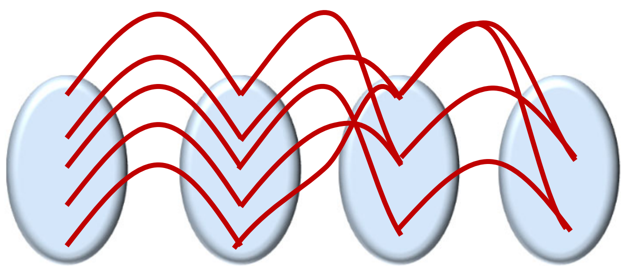
Jane	A	Business	21	Part-time
Lisa	B	Chemistry	21	Part-time
Mary	C	Biology	19	Full-time
Nancy	B	Biology	19	Full-time
Paul	B	Business	21	Part-time

Table 2.2. Equivalence Relation R_g D
Table 2.1 with Res

R_g	A	B	C	D	G
A	1	0	0	0	0
B	0	1	1	0	0
C	0	1	1	0	0
D	0	0	0	1	1
G	0	0	0	1	1
J	0	0	0	1	1
L	1	0	0	0	0
M	0	1	1	0	0
N	1	0	0	0	0
P	1	0	0	0	0



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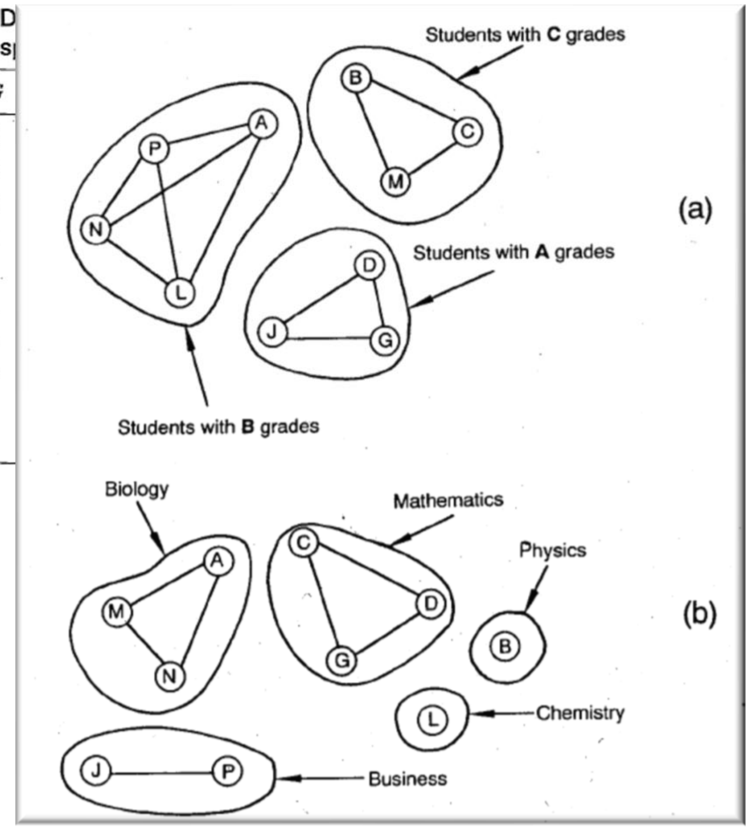

Note: same <u>thinghood</u> (set of students), but distinct <u>systemhood</u> or organization projected to a specific set (layer) as equivalence classes.

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study of “systemhood” separated from “thinghood”

- Study of “systemhood” properties
  - Classes of isomorphic abstracted systems
  - Search of **general principles** of **organization**
    - Weaver’s organized complexity (1948)
- Systemhood properties
  - preserved under suitable transformation from the set of things of one system into the set of things from the other system
    - Divides the space of possible systems (relations) into equivalent classes
- Devoid of any interpretation!
  - General systems
    - Canonical examples of equivalence classes

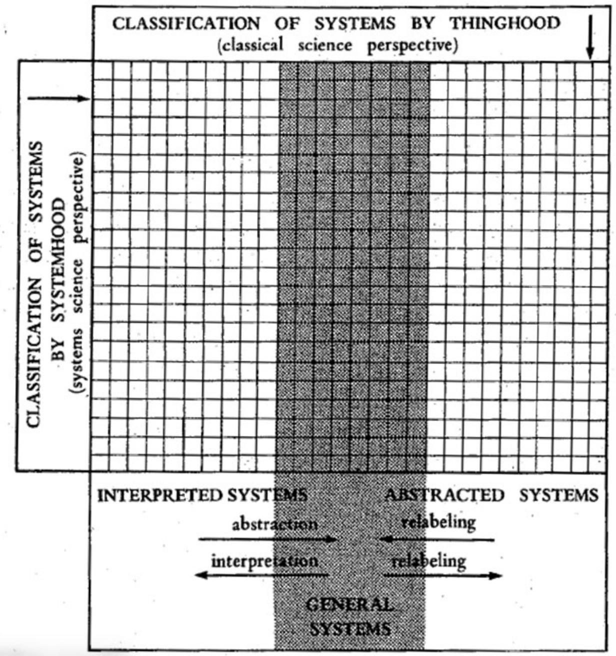

Figure 2.6. Two ways of classifying systems and the role of general systems.

From Klir [2001]

readings

- Class Book
  - Klir, G.J. [2001]. *Facets of systems science*. Springer.
- Papers and other materials
  - Module 2: Systems Science
    - Reading and Discussion Group 4
      - Klir, G.J. [2001]. *Facets of systems Science*. Springer. Chapter 8.
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