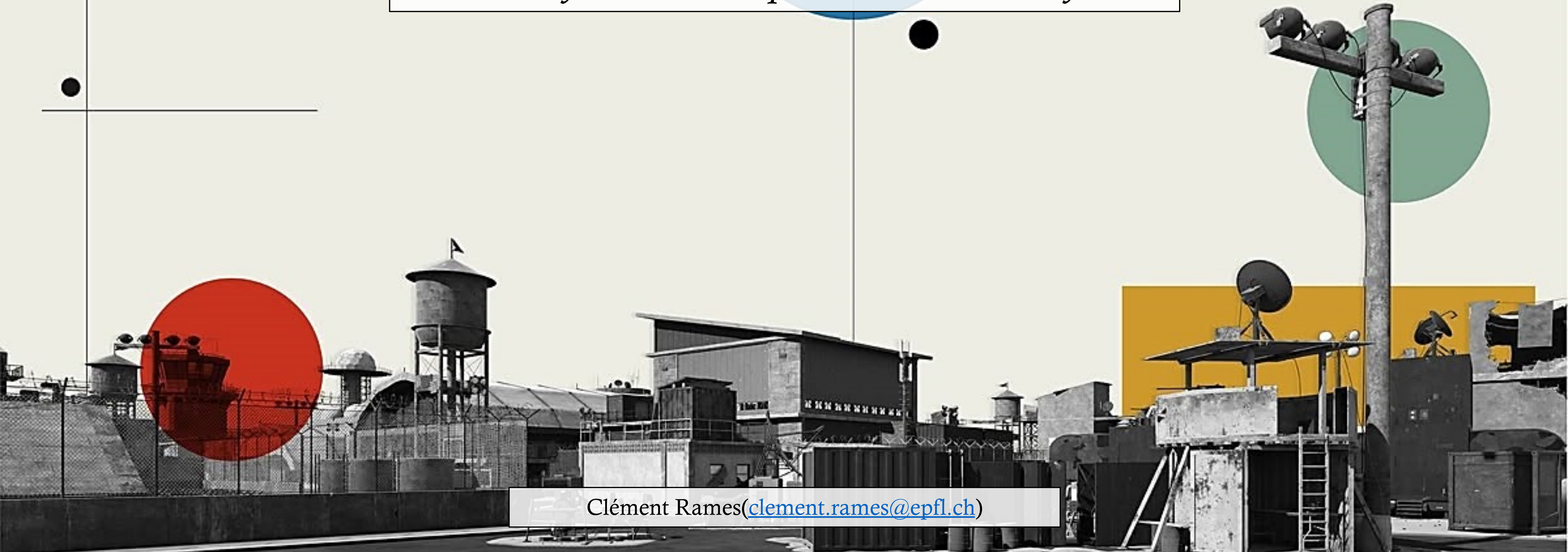
EPFL

Computational Methods in Urban Studies

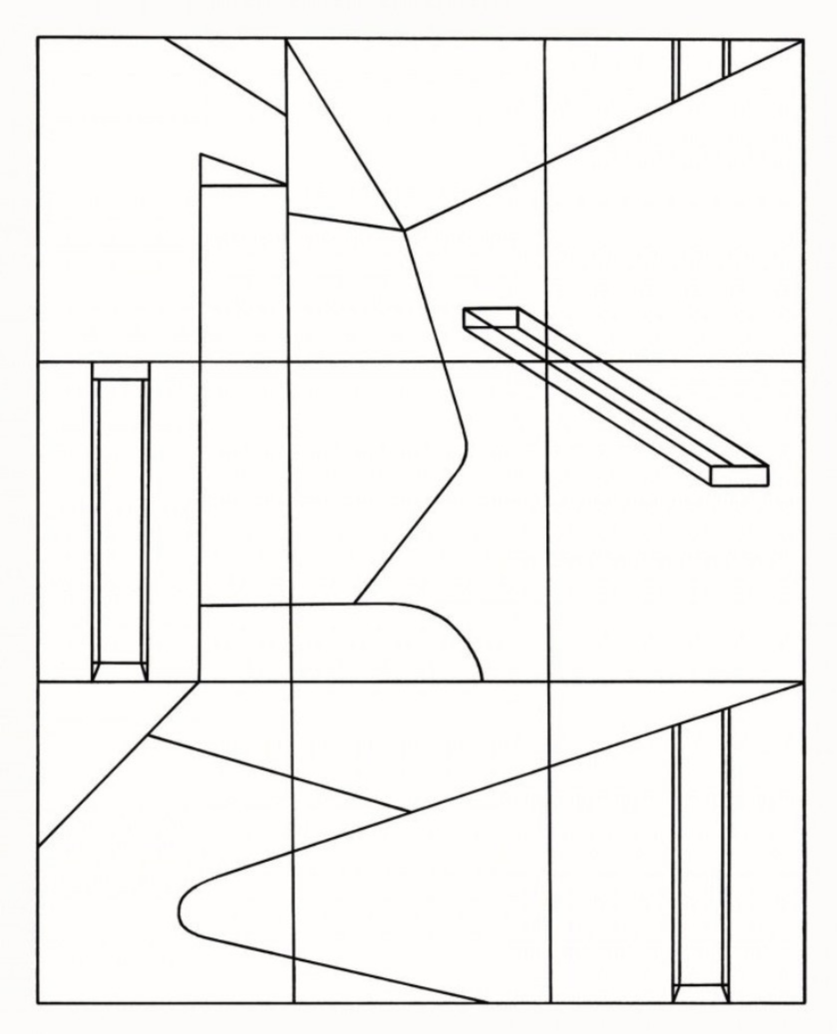
Week 9 : Systems – Complex sociotechnical systems



Clément Rames(clement.rames@epfl.ch)

Plan

réf.: Alban Loosli, Exhibiting the White Cube, sustema press↓



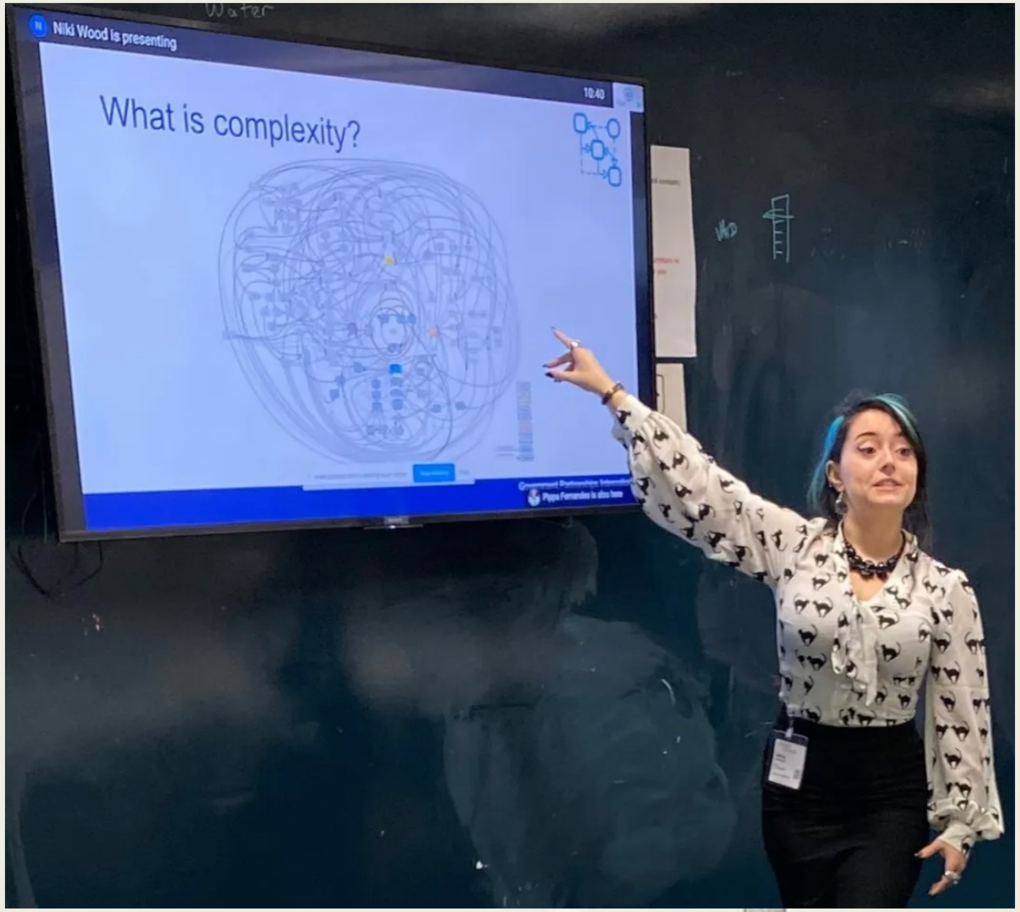
1. **Systems**
   → Donella Meadows & limits to growth: the world3 model, system structure, system dynamics, leverage points
2. **Complexity**
   → A century of complexity: Bolsheviks, Nazis & Americans
   → Edgar Morin: human complexity
   → Bruno Latour: Actor Network Theory
3. **Networks**
   → Social Networks (Brandes)
   → Spatial Networks (Barthélémy)
4. **Recent applications to urban/sociotechnical systems**

The Plot

réf.: rebelwithcausation.com/complexity-101/↓

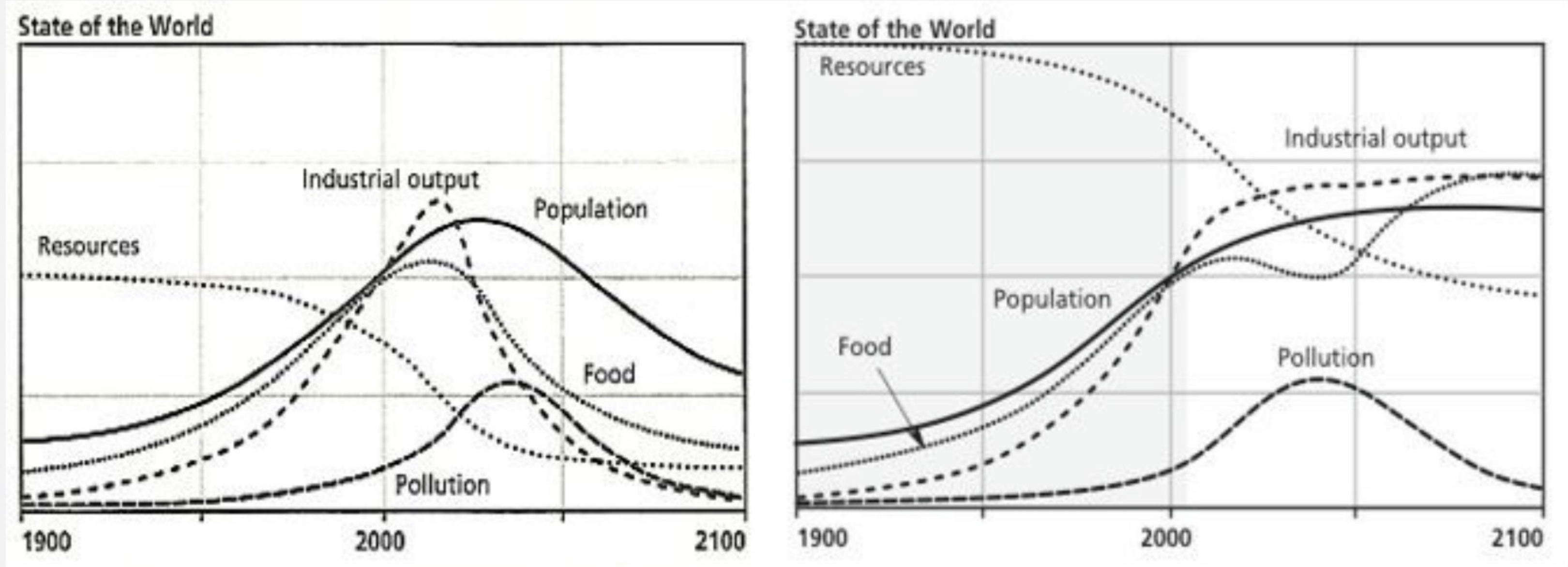
- **What is a system?**
  - → Each of you defines “system” in 1 sentence
  - → From greek: σύστημα, "whole concept made of several parts or members, composition”
  - → ***The whole is more than the sum of its parts*** (Aristotle, “holism”)
  - → **S** = (T, R)
  - → What, then, is an *Urban System?*

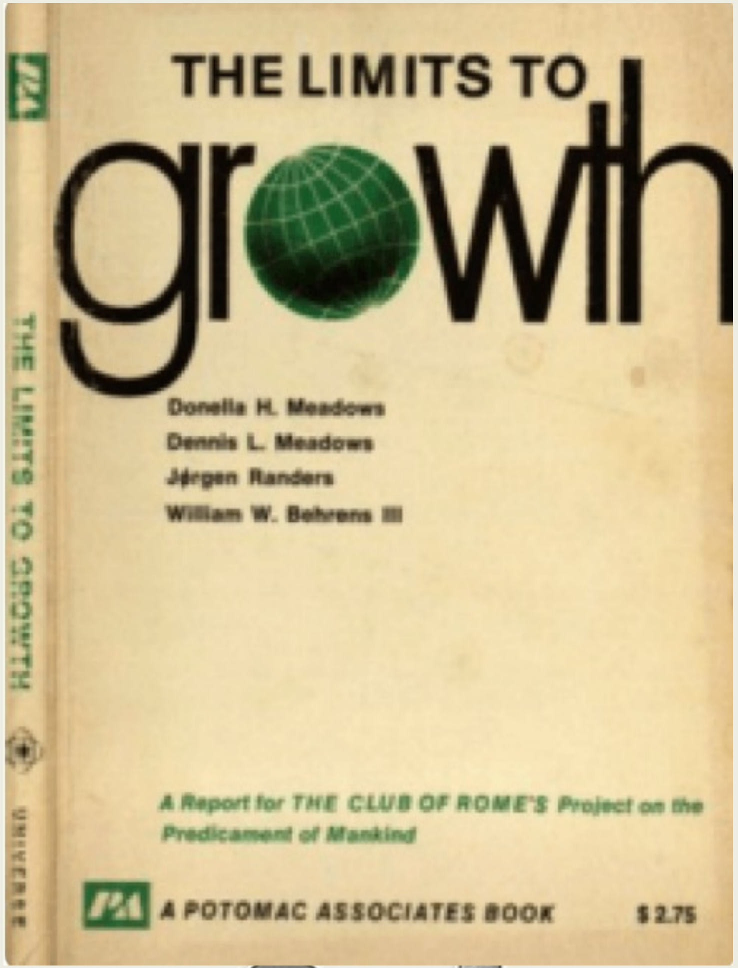
> *What is a system? As any poet knows, a system is a way of looking at the world. -G. Weiberg*



The Plot

- **The world3 model**
  - → Limits to growth (Meadows et al.,1972)
  - → https://youtu.be/A_BtS008J0k?si=4-pmyQYNFN0Zy7Rf



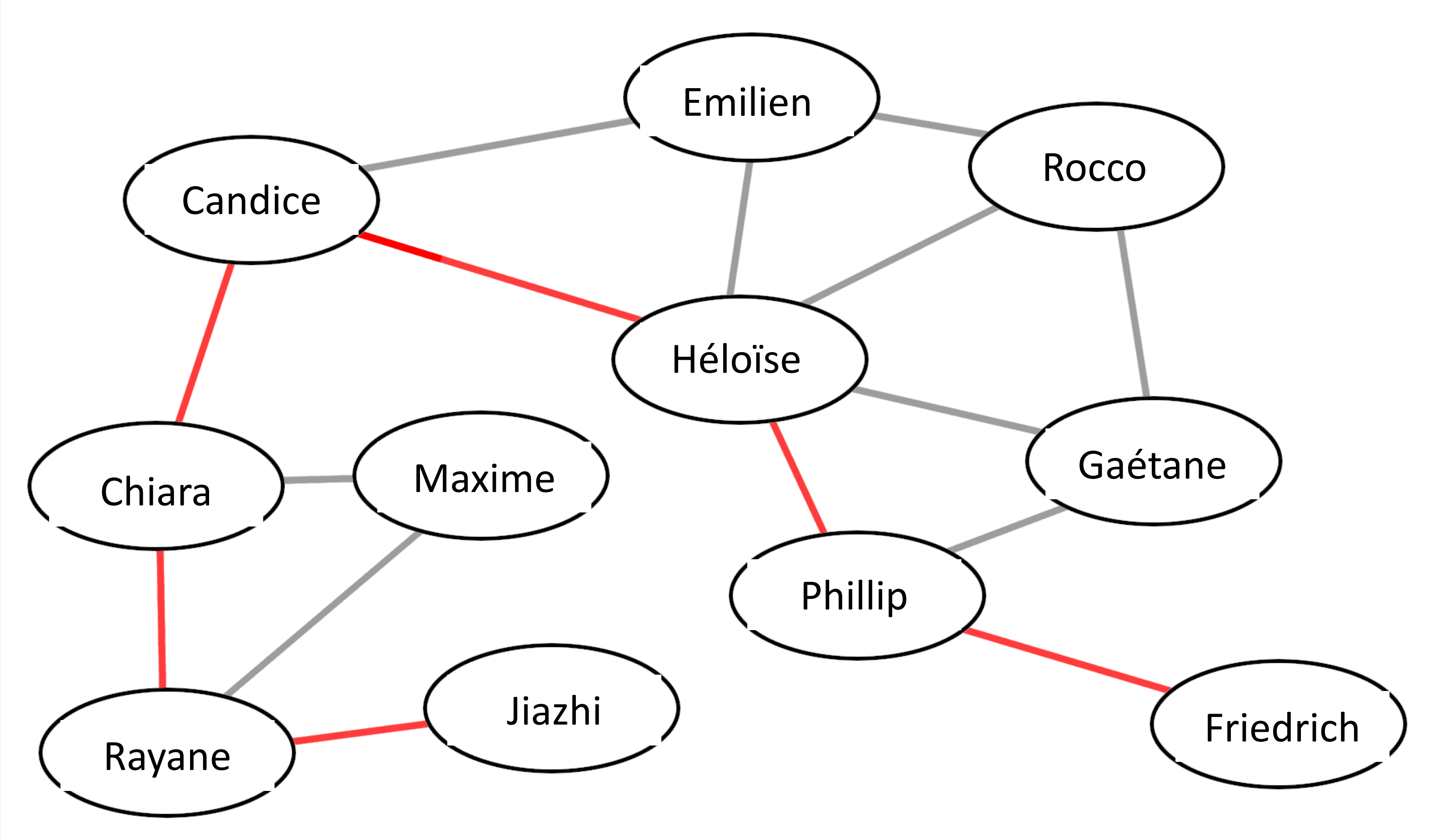


The Plot

- **Introducing social networks**
  → 6 degrees of separation?

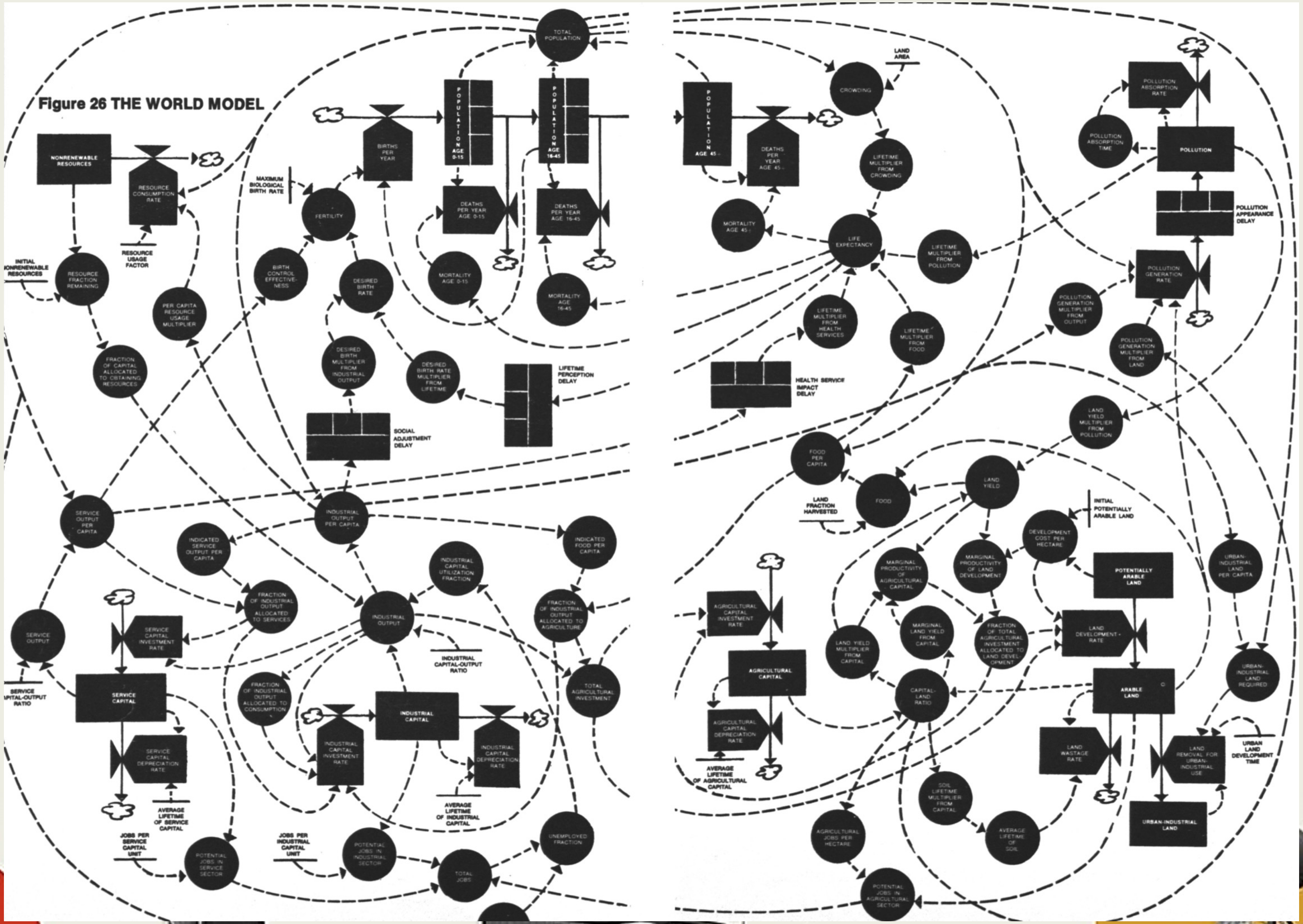
- **Other examples of networks**
  → Social, infrastructural, technological, ecological

réf.: *Wikipedia*↓



1. Systems

réf.: Limits to Growth→



1. Systems

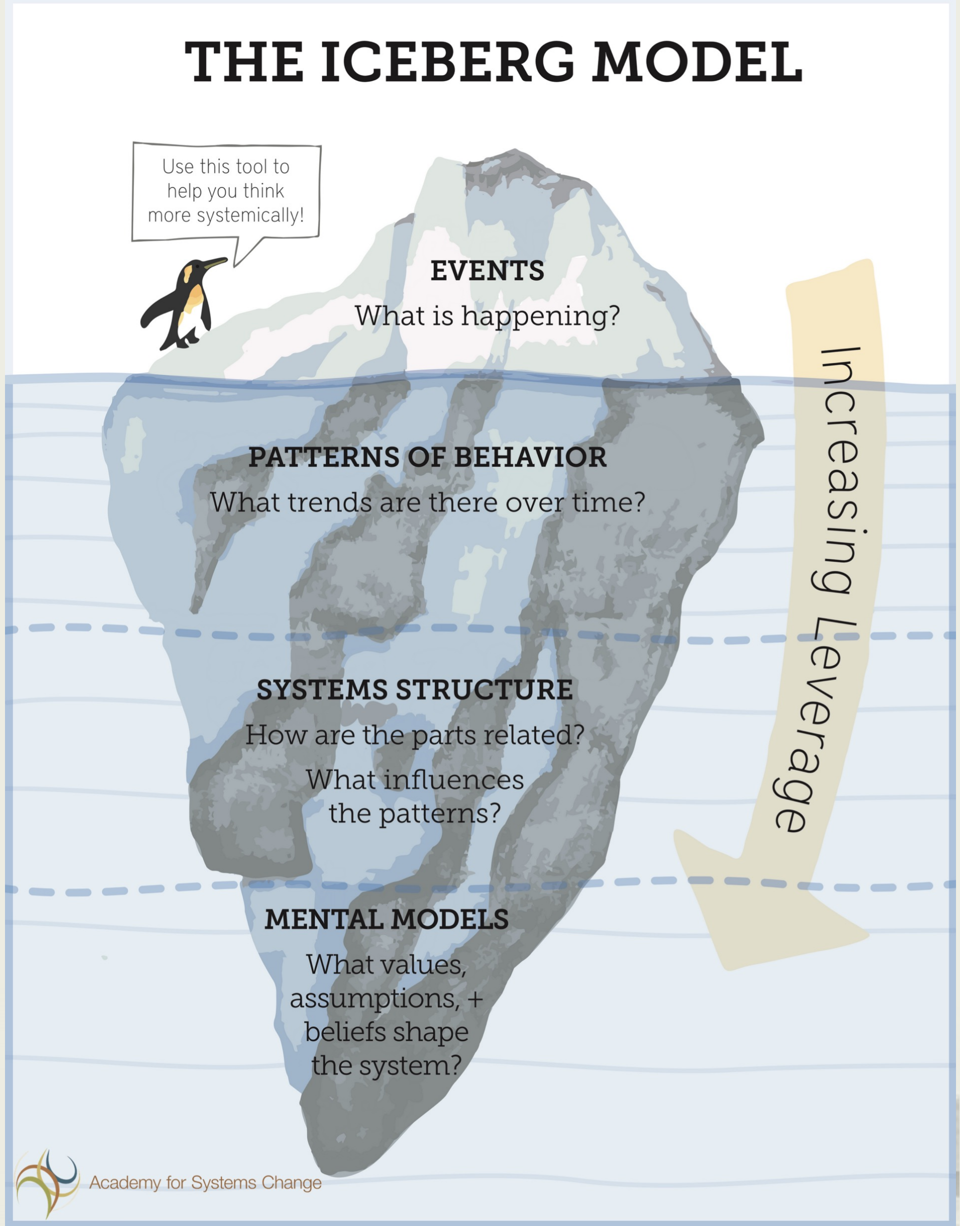
réf.: Donella Meadows↓

- **System structure**

"Like the tip of an iceberg rising above the water, events are the most visible aspect of a larger complex—but not always the most important. […] When a systems thinker encounters a problem, the first thing he or she does is look for data, time graphs, the history of the system. That's because long-term behavior provides clues to the underlying system structure. And structure is the key to understanding not just what is happening, but why."

→ To understand system structure, we first need to identify its stocks, flows and feedback loops.

→ **Exercise**: go through the iceberg model for your project



1. Systems

réf.: Limits to Growth, 1972↓

- **System dynamics**

> *"Systems of information-feedback control are fundamental to all life and human endeavor, from the slow pace of biological evolution to the launching of the latest space satellite. Everything we do as individuals, as an industry, or as a society is done in the context of an information-feedback system."*

→ What are the feedback mechanisms in your system?

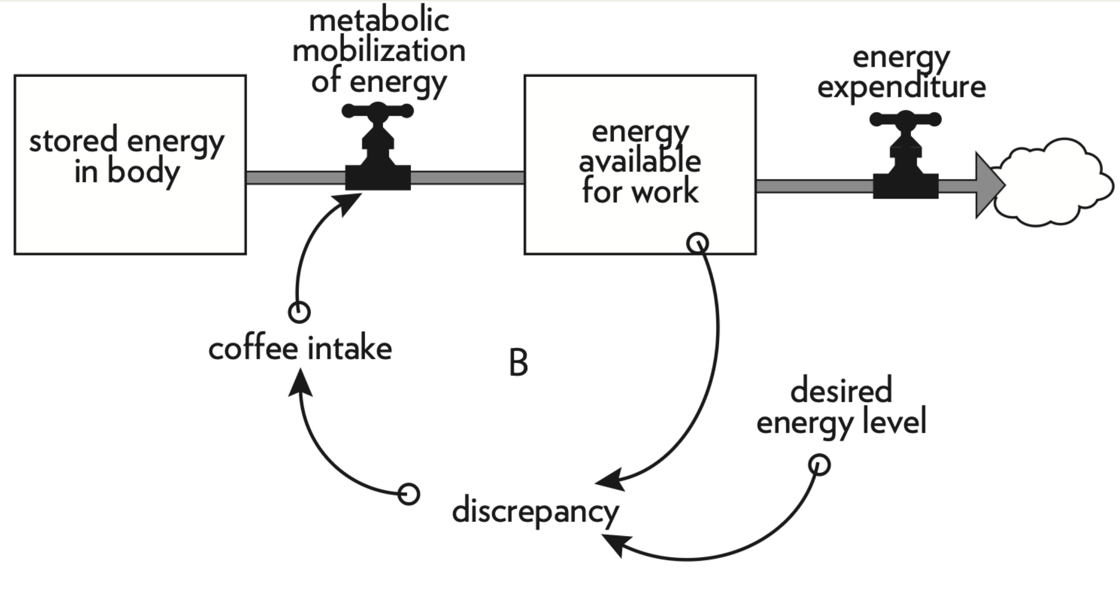
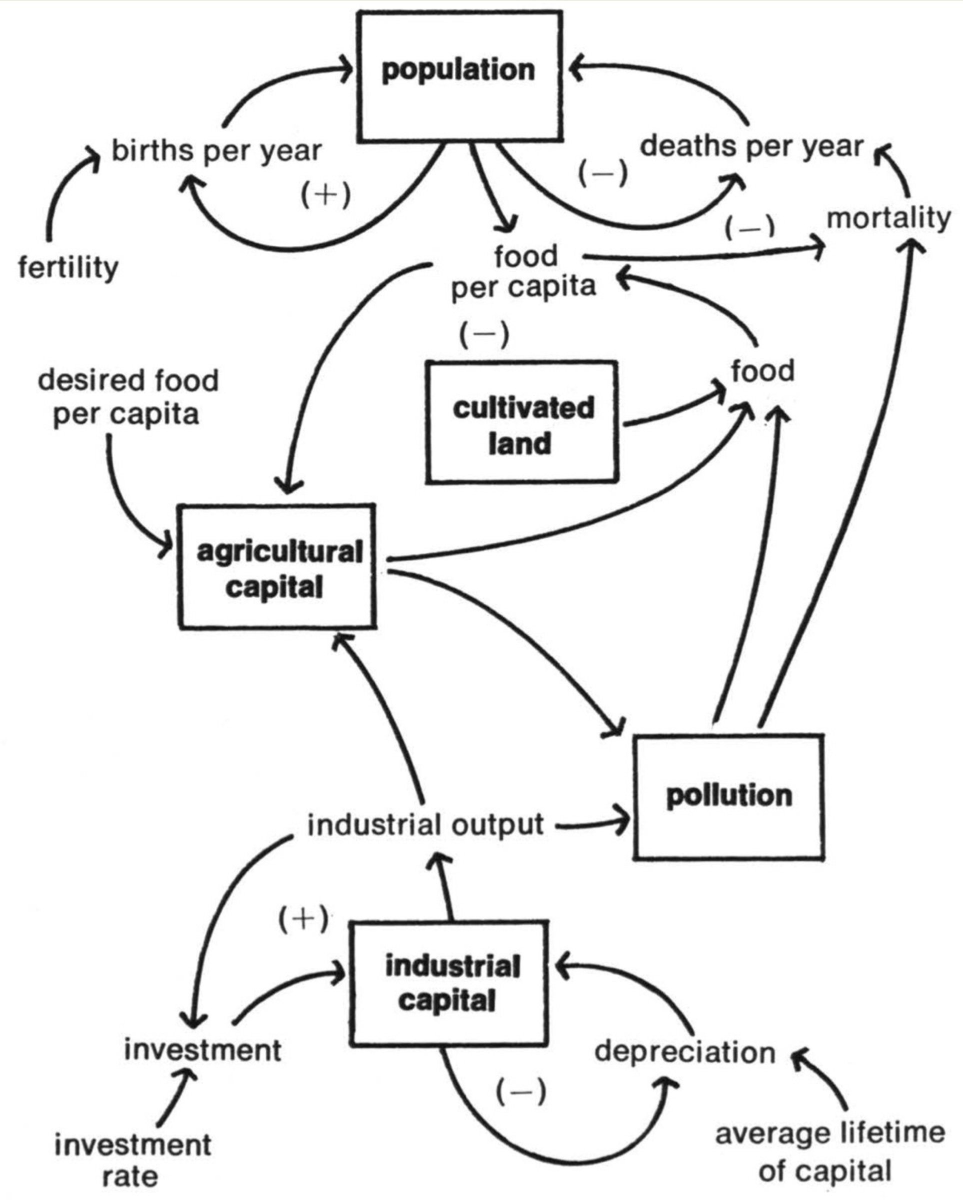


Figure 9. Energy level of a coffee drinker.



1. Systems

réf.: Donella Meadows, Thinking in Systems↓

- **Leverage points**

> *"MIT's Jay Forrester likes to say that the average manager can **define the current problem** very cogently, **identify the system structure** that leads to the problem, and guess with great accuracy **where to look for leverage points**—places in the system where a small change could lead to a large shift in behavior. […] But Forrester goes on to point out that although people deeply involved in a system often know intuitively where to find leverage points, more often than not **they push the change in the wrong direction**."*

→ Back to the world3 model: is economic growth the solution or… the root cause of the problem?

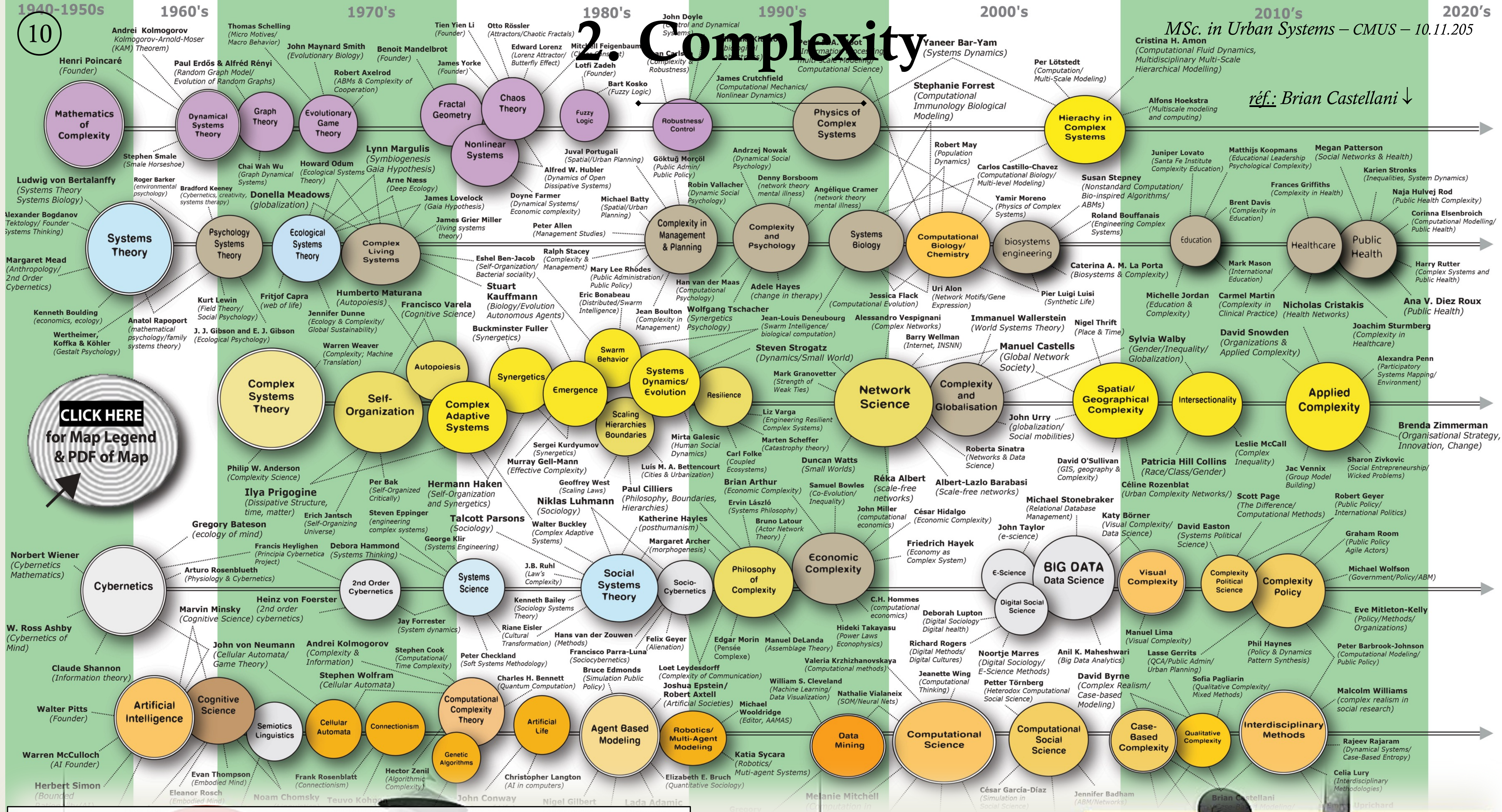
Places to Intervene in a System
(in increasing order of effectiveness)

12. **Numbers:** Constants and parameters such as subsidies, taxes, and standards
11. **Buffers:** The sizes of stabilizing stocks relative to their flows
10. **Stock-and-Flow Structures:** Physical systems and their nodes of intersection
9. **Delays:** The lengths of time relative to the rates of system changes
8. **Balancing Feedback Loops:** The strength of the feedbacks relative to the impacts they are trying to correct
7. **Reinforcing Feedback Loops:** The strength of the gain of driving loops
6. **Information Flows:** The structure of who does and does not have access to information
5. **Rules:** Incentives, punishments, constraints
4. **Self-Organization:** The power to add, change, or evolve system structure
3. **Goals:** The purpose of the system
2. **Paradigms:** The mind-set out of which the system—its goals, structure, rules, delays, parameters—arises
1. **Transcending Paradigms**

2. Complexity

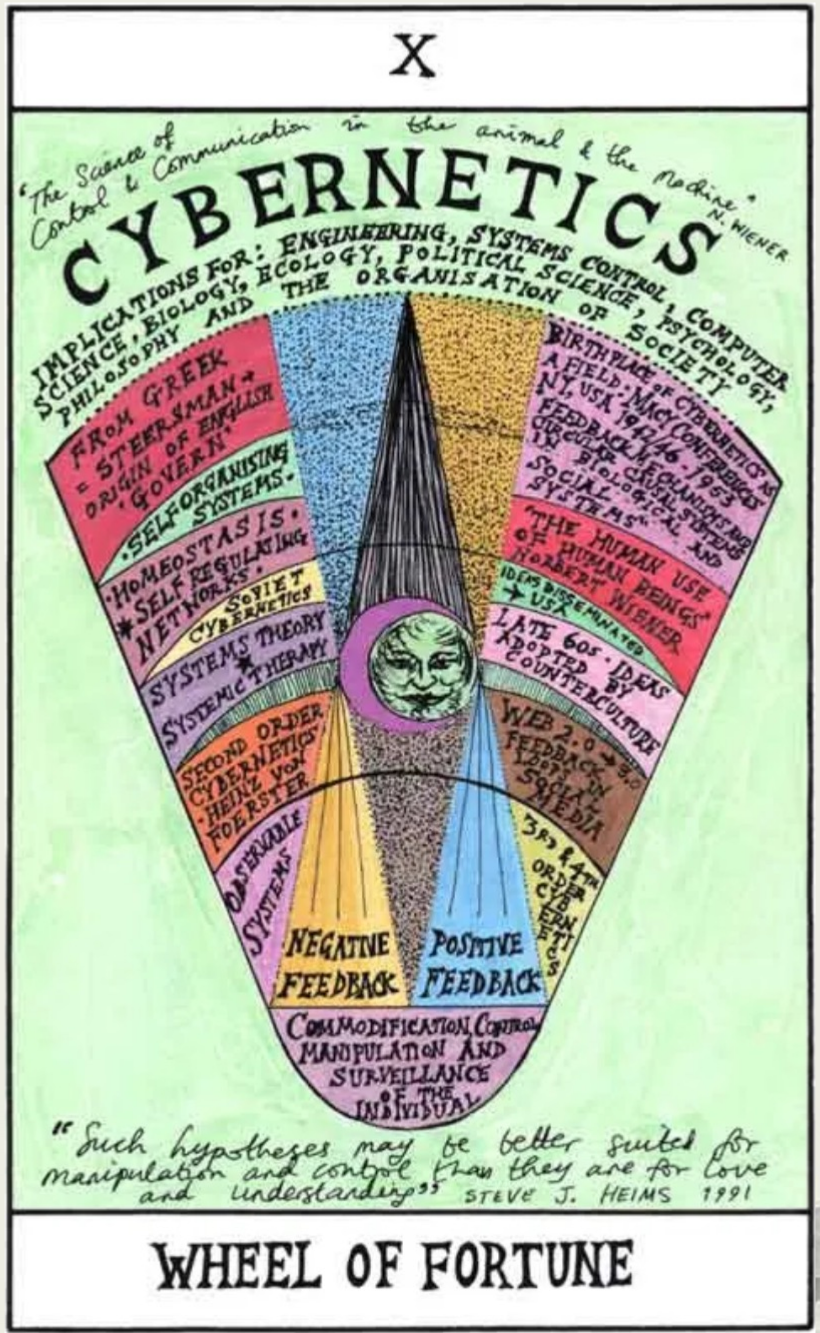
MSc. in Urban Systems – CMUS – 10.11.205

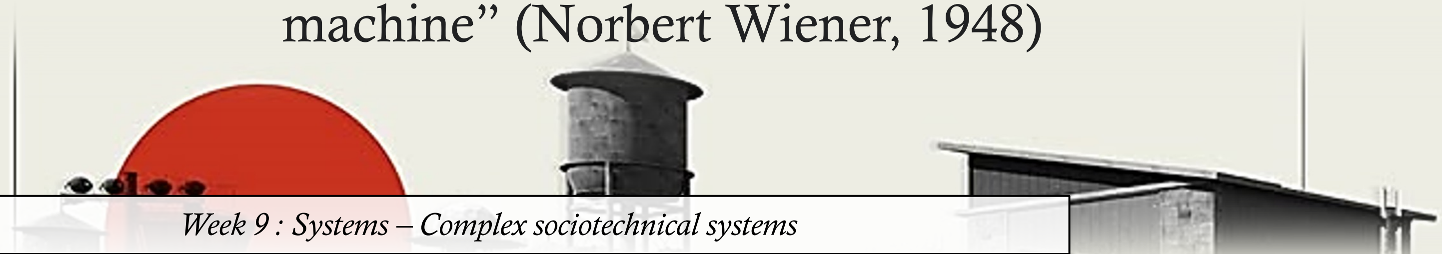
réf.: Brian Castellani ↓



2. Complexity

- **Tektology**
  - → Tektology ~ Universal Organization Science
  - → “All things are organizational, all complexes can only be understood through their organizational character.” (Aleksander Bogdanov, 1922)
- **General systems theory**
  - → Zu einer allgemeinen Systemlehre (Ludwig Von Bertalanffy, 1945) rooted in biology, living systems
- **Cybernetics**
  - → From Greek κυβερνήτης : “the person who steers a ship”
  - → The transdisciplinary science of feedback mechanisms
  - → “Control and communication in the animal and the machine” (Norbert Wiener, 1948)



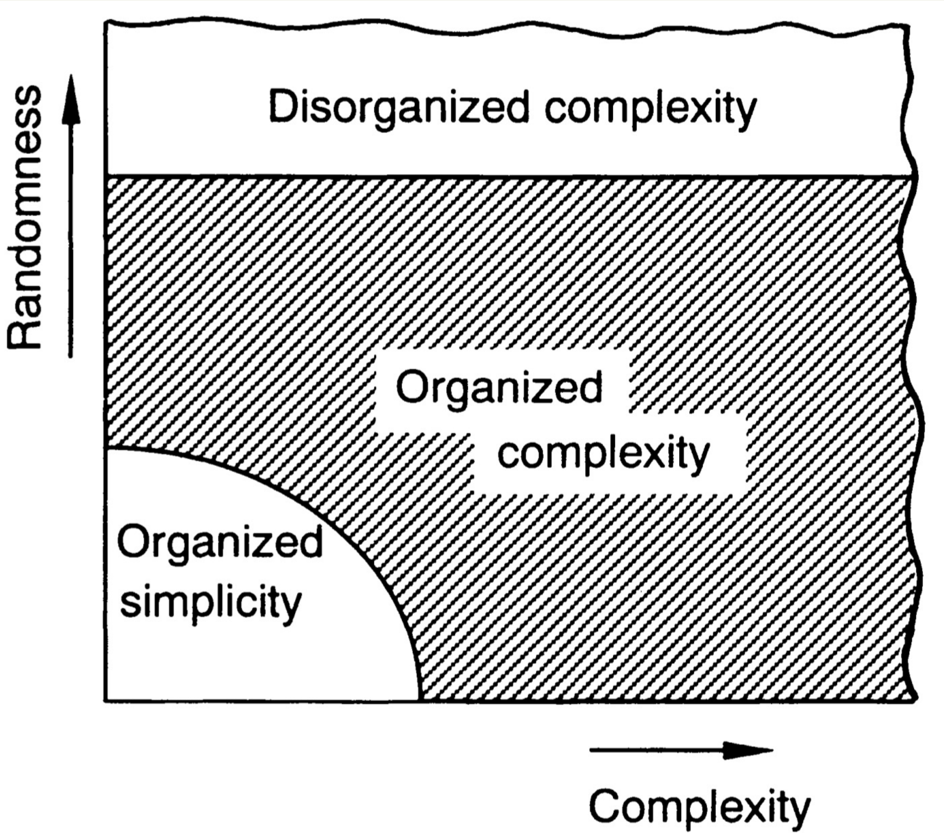


2. Complexity

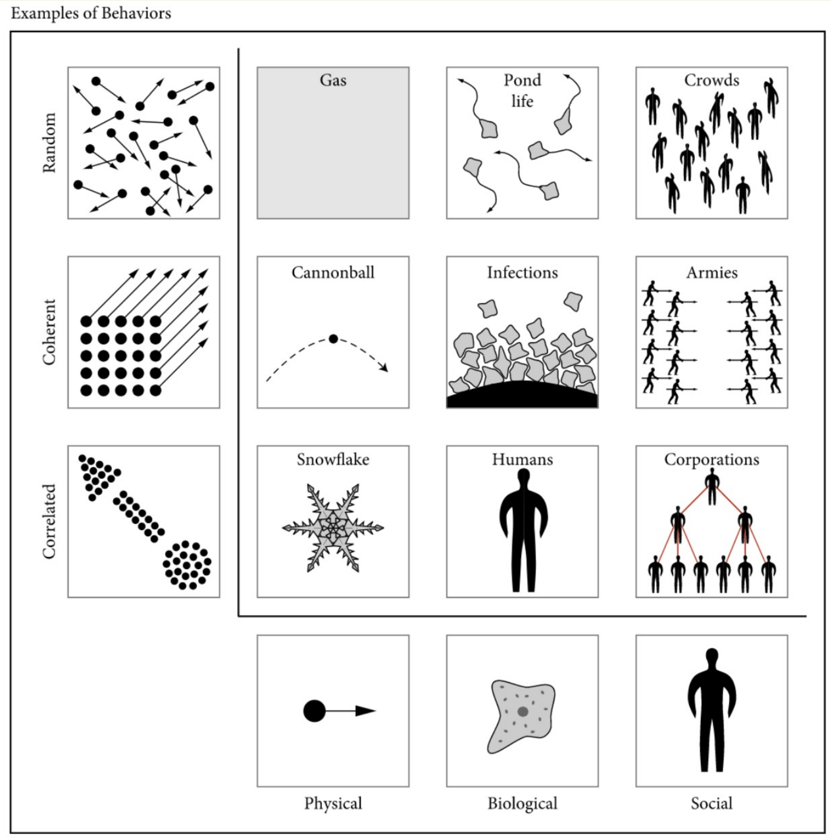
- **Some properties of complex systems:**
  - → Self-organization
  - → Nestedness
  - → Adaptation
  - → Emergence
  - → Non-linearity
  - → Feedback loops
  - → Critical transitions

Further reading: Facets of Systems Science, G. Klir

réf.: Weaver, 1948↓



réf.: Siegenfeld & Bar-Yam, 2020↓



2. Complexity

- **Complexity thinking (Edgar Morin)**
  → From latin *com-plexus* – "woven together"
  → https://youtu.be/amn-AkvwOsA?si=3W85gREBTg-9Ci2S

"complexity science is not the sudden awareness on the part of scientists that the world is complex. That the world is complex is an obvious fact. What made complexity science possible—and this is why we can argue that it is more a methodological, rather than theoretical revolution—is that scientists finally created a set of methods that could model this complexity." F. Capra

2. Complexity

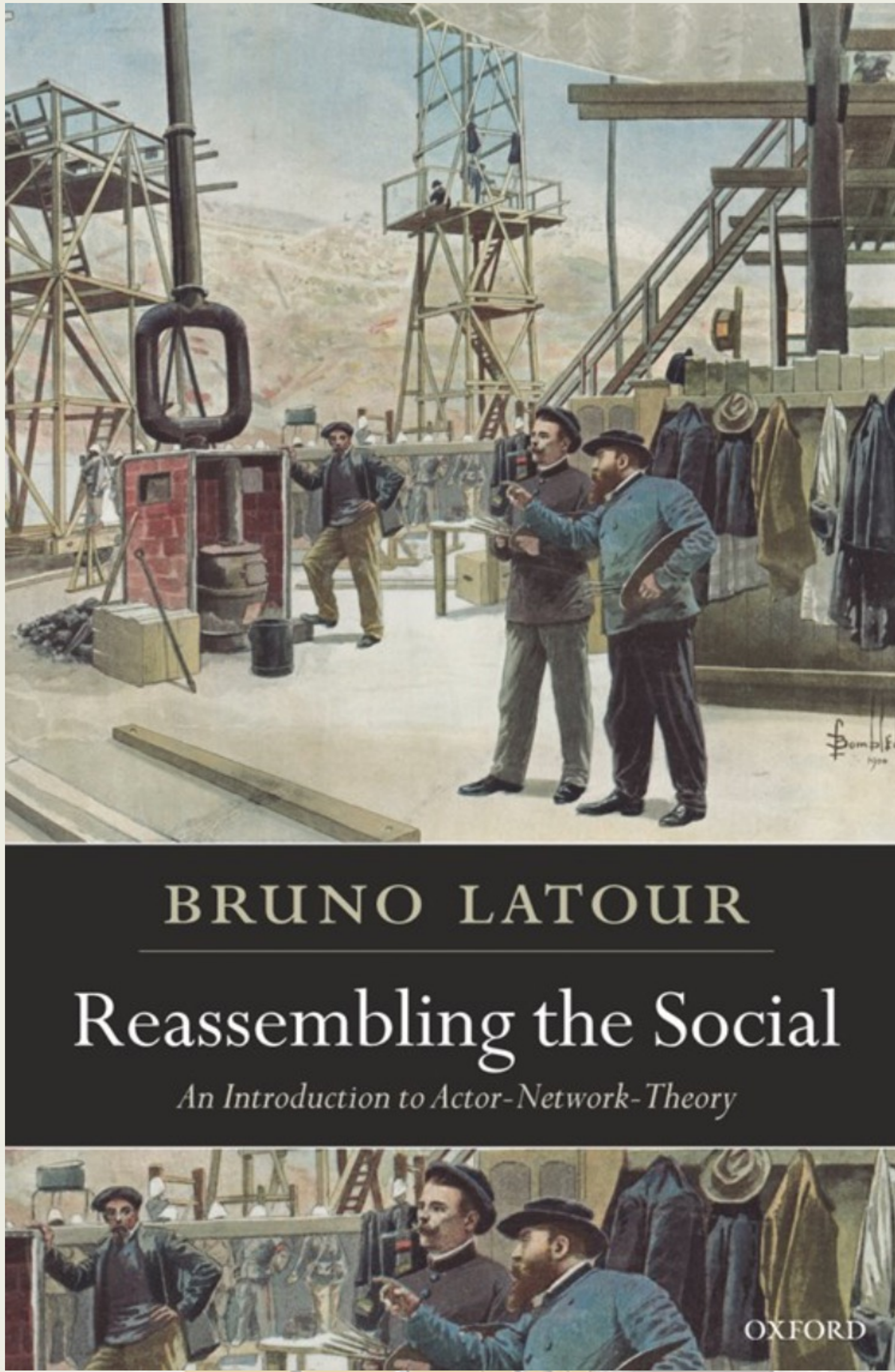
- **Actor Network Theory (Bruno Latour)**

"the question of the social emerges when the ties in which one is entangled begin to unravel; the social is further detected through the surprising movements from one association to the next; those movements can either be suspended or resumed; when they are prematurely suspended, the social as normally construed is bound together with already accepted participants called 'social actors' who are members of a 'society'; when the movement toward collection is resumed, it traces the social as associations through many non-social entities which might become participants later; if pursued systematically, this tracking may end up in a shared definition of a common world, what I have called a collective; but if there are no procedures to render it common, it may fail to be assembled; and, lastly, sociology is best defined as the discipline where participants explicitly engage in the reassembling of the collective" - B. Latour

On actor-network theory. A few clarifications plus more than a few complications

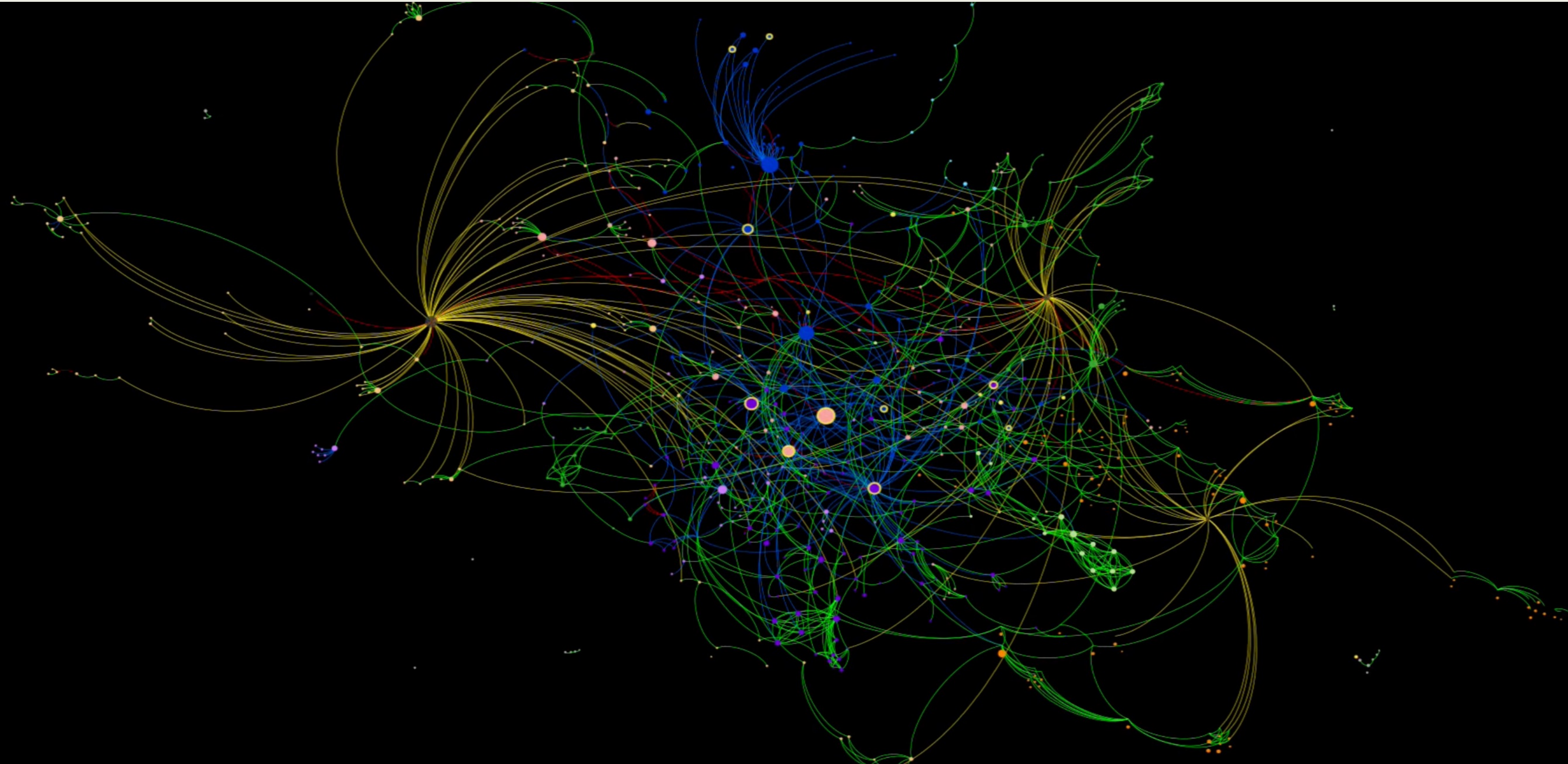
😂😂😂😂

Bruno Latour



3. Networks

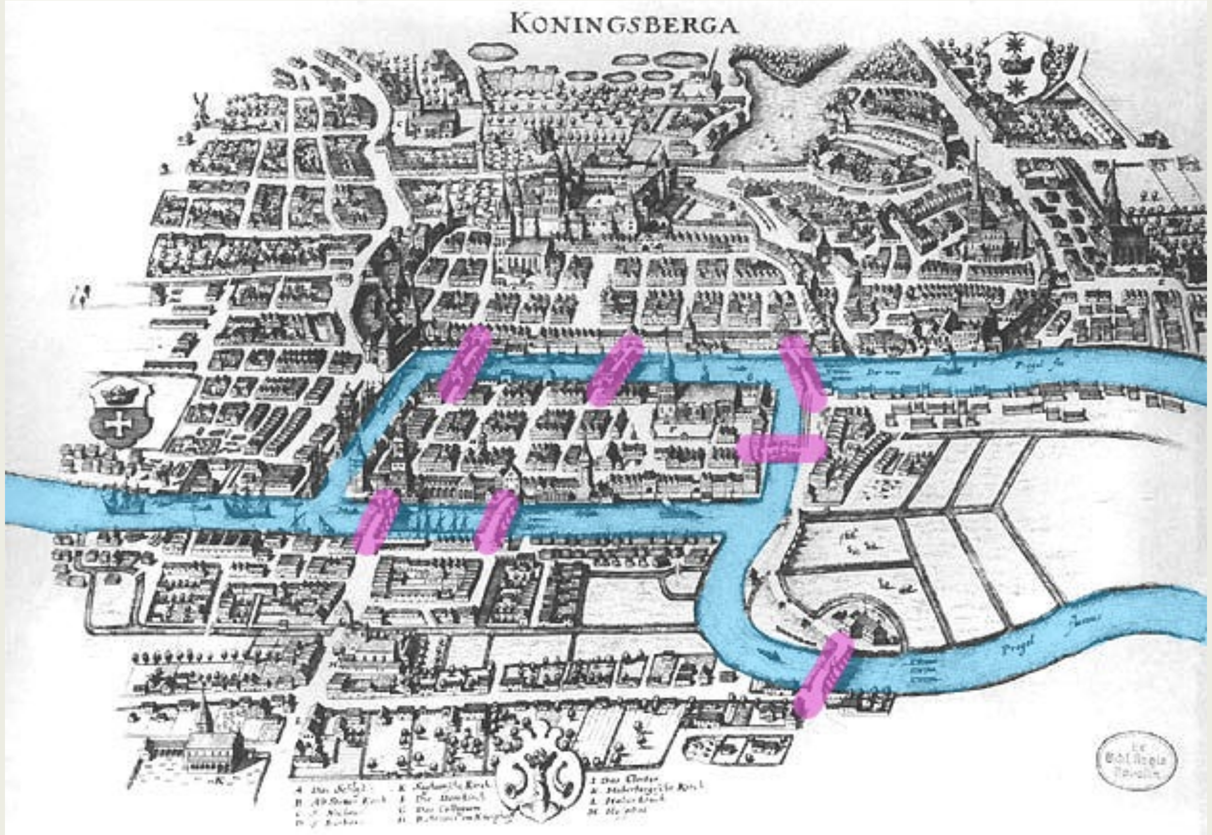
réf.: despojo-uraba.forensic-architecture.org ↓

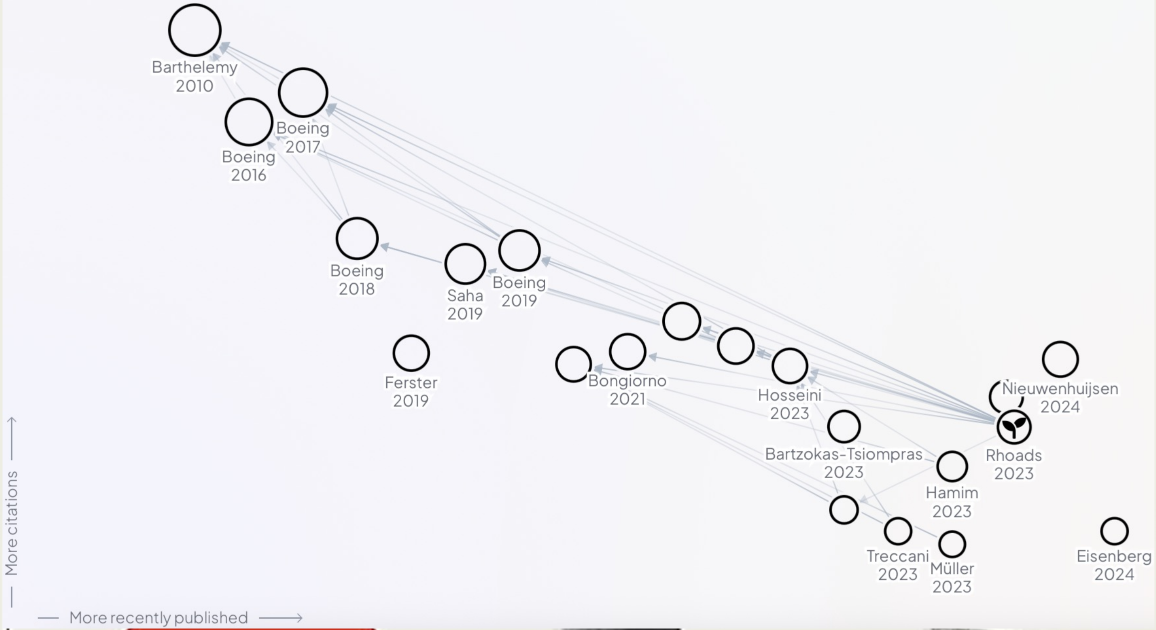


3. Networks

- **From Euler to Twitter**
  - → The seven bridges of Königsberg (Leonhard Euler, 1736)
  - → Access to large-scale Twitter datasets (2010's) → boom of network science

réf.: Wikimedia↓





← réf.:Research Rabbit

3. Networks

réf.: snap.stanford.edu/data/ ↓

- **Social networks:**
  - → Directed / undirected networks
  - → Weighted / unweighted networks
  - → Bipartite networks
  - → Multigraph: network has multiple edges between a pair of nodes
  - → Temporal: for each node/edge we know the time when it appeared in the network
  - → Labeled: network contains labels (weights, attributes) on nodes &/edges

Stanford Large Network Dataset Collection

- Social networks : online social networks, edges represent interactions between people
- Networks with ground-truth communities : ground-truth network communities in social and information networks
- Communication networks : email communication networks with edges representing communication
- Citation networks : nodes represent papers, edges represent citations
- Collaboration networks : nodes represent scientists, edges represent collaborations (co-authoring a paper)
- Web graphs : nodes represent webpages and edges are hyperlinks
- Amazon networks : nodes represent products and edges link commonly co-purchased products
- Internet networks : nodes represent computers and edges communication
- Road networks : nodes represent intersections and edges roads connecting the intersections
- Autonomous systems : graphs of the internet
- Signed networks : networks with positive and negative edges (friend/foe, trust/distrust)
- Location-based online social networks : social networks with geographic check-ins
- Wikipedia networks, articles, and metadata : talk, editing, voting, and article data from Wikipedia
- Temporal networks : networks where edges have timestamps
- Twitter and Memetracker : memetracker phrases, links and 467 million Tweets
- Online communities : data from online communities such as Reddit and Flickr
- Online reviews : data from online review systems such as BeerAdvocate and Amazon
- User actions : actions of users on social platforms.
- Face-to-face communication networks : networks of face-to-face (non-online) interactions
- Graph classification datasets : disjoint graphs from different classes
- Computer communication networks : communications among computers running distributed applications
- Cryptocurrency transactions : transactions covering several cryptocurrencies and exchanges
- Telecom networks : relationships between users, packages, apps, and cells in a telecom network

3. Networks

réf.: Barthélémy, 2010↓

- **Spatial networks**
  - → Networks embedded in physical space
  - → Importance of network topography!
  - → Particularly relevant to transportation
  - → But also: energy, telecommunications

3. Networks

réf.: *National Geogrpahic*↓

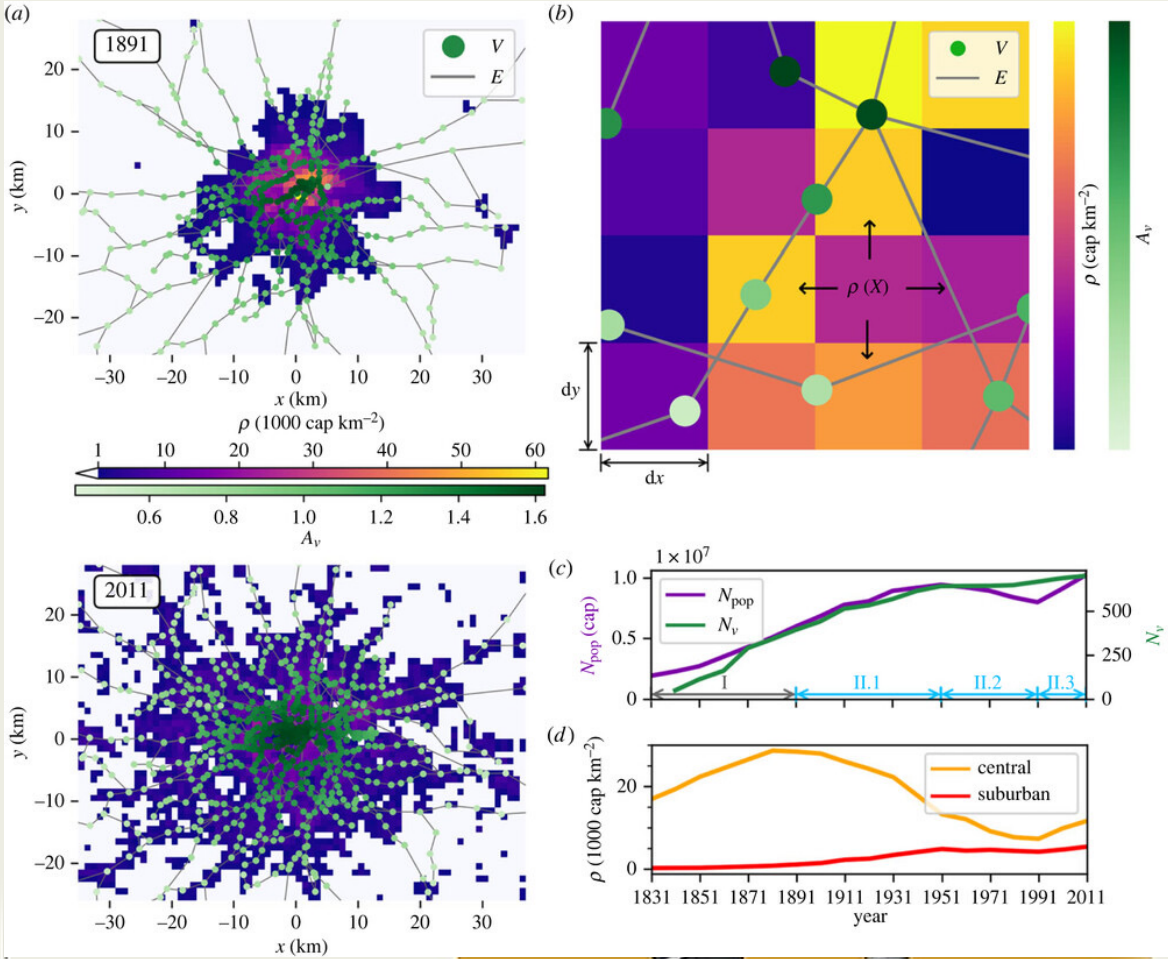
- **Feedback loops in ecological networks**
  - → Ecosystems can be studied as networks, e.g. plant-pollinator mutualistic networks
  - → “Trophic cascades” → system reconfiguration
  - → Reintroduction of wolves caused a change in the Yellowstone river course
  - → https://youtu.be/W88Sact1kws?si=2xT_QKQcZuHG3ZAR

3. Networks

réf.: Capel-timms et al., 2024↓

- **Urban networks: transport X urban growth**
  - → Modeling the ***angiogenic*** growth of cities
  - → *Angiogenesis* = growth of new blood vessels
  - → Complex population–transport feedback loops
  - → Growth of urbanization and rail network modeled conjointly in London 1831-2011
  - → So, transport network planning is CRUCIAL!

https://royalsocietypublishing.org/doi/10.1098/rsif.2023.0657



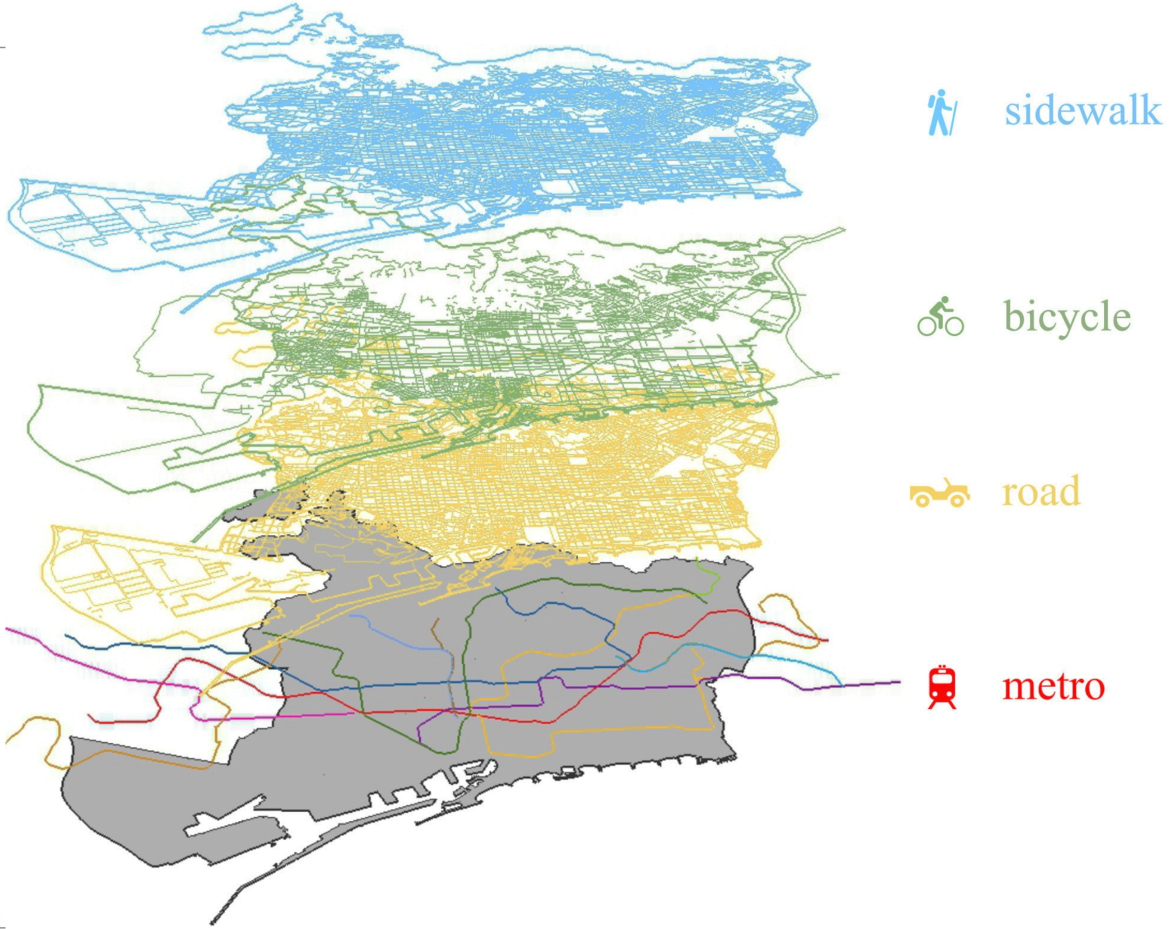
4. Applications to urban/sociotechnical systems

réf.: Rhoads et al., 2023 ↓

- **Sidewalk Networks**
  - → Use OpenStreetMaps or computer visition to build sidewalk networks
  - → Flow estimation based on betweenness centrality
  - → Model multimodal transport as multilayer network
  - → Social Interaction Potential

https://www.sciencedirect.com/science/article/pii/S0198971523000947

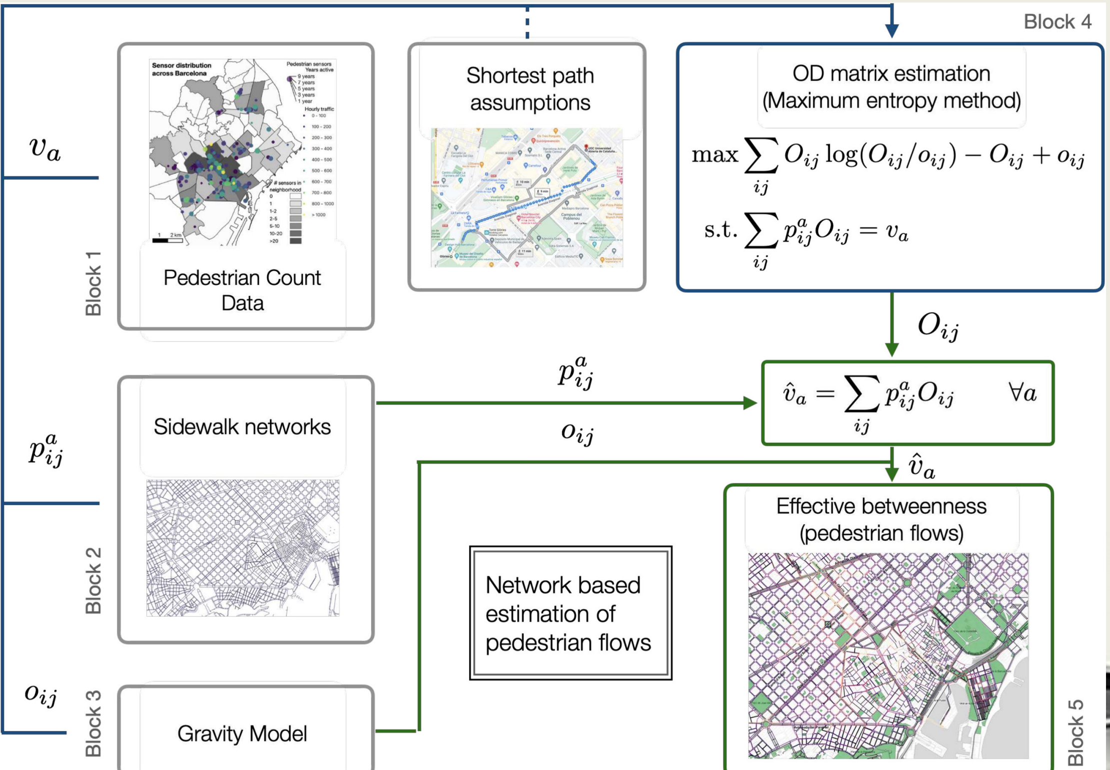
City	Metric	Sidewalk network
Boston	N	46,547
	E	96,022
	$\langle k \rangle$	4.13
	$\langle Eff \rangle$	9.8×10^{-5}
	D	23,823 m
New York	N	129,520
	E	253,594
	$\langle k \rangle$	3.91
	$\langle Eff \rangle$	5.4×10^{-5}
	D	39,226 m
Paris	N	40,095
	E	62,414
	$\langle k \rangle$	3.11
	$\langle Eff \rangle$	1.1×10^{-4}
	D	22,427 m

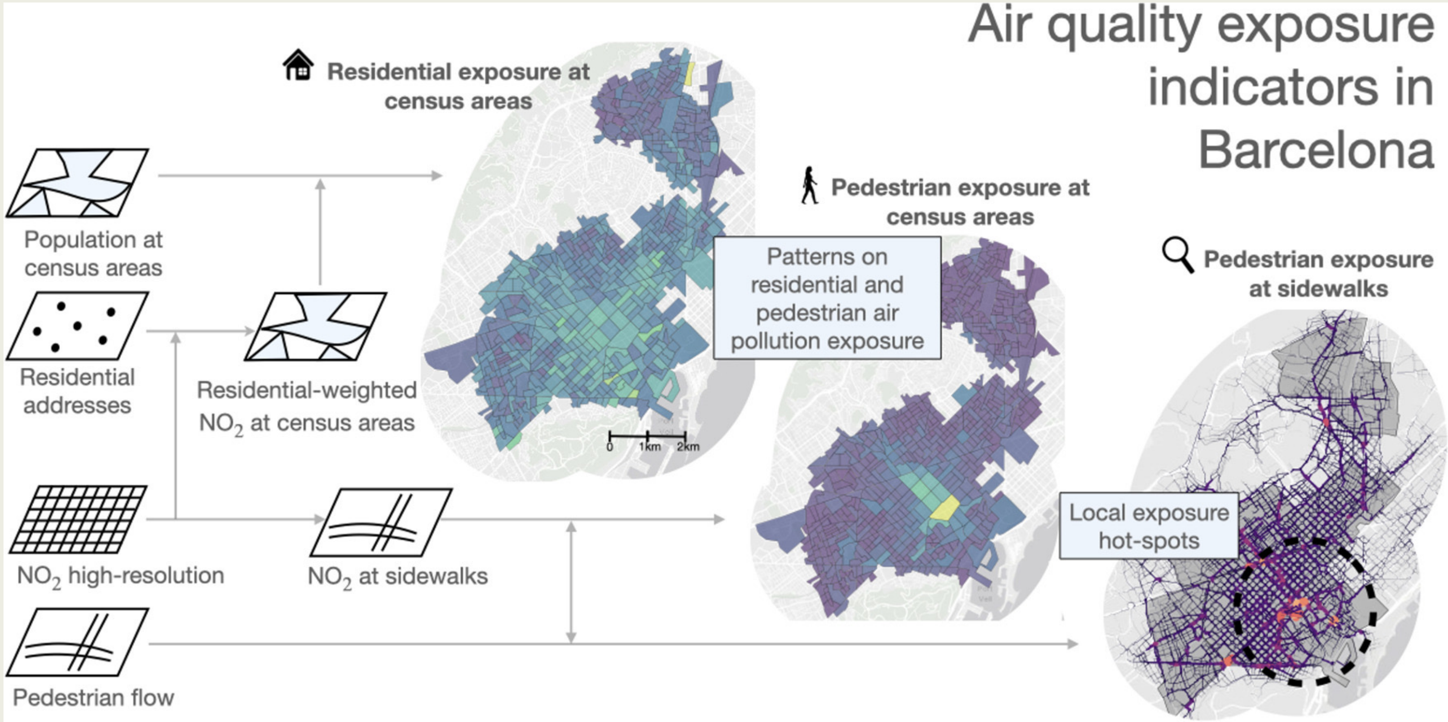


4. Applications to urban/sociotechnical systems

réf.: Armengol et al., 2024↓

- **City-scale assessment of pedestrian exposure to air pollution: a case study in Barcelona**





→ Pedestrian flow estimation on sidewalk network

→ High-resolution spatio-temporal air quality model

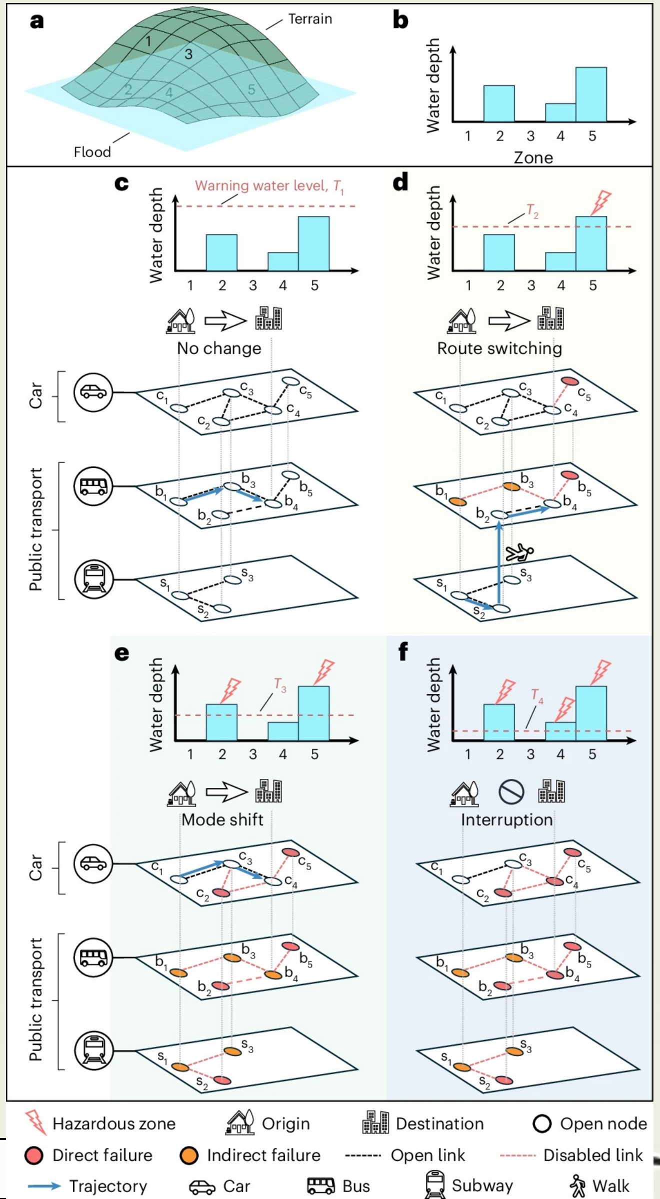
https://www.sciencedirect.com/science/article/pii/S2212095524003808

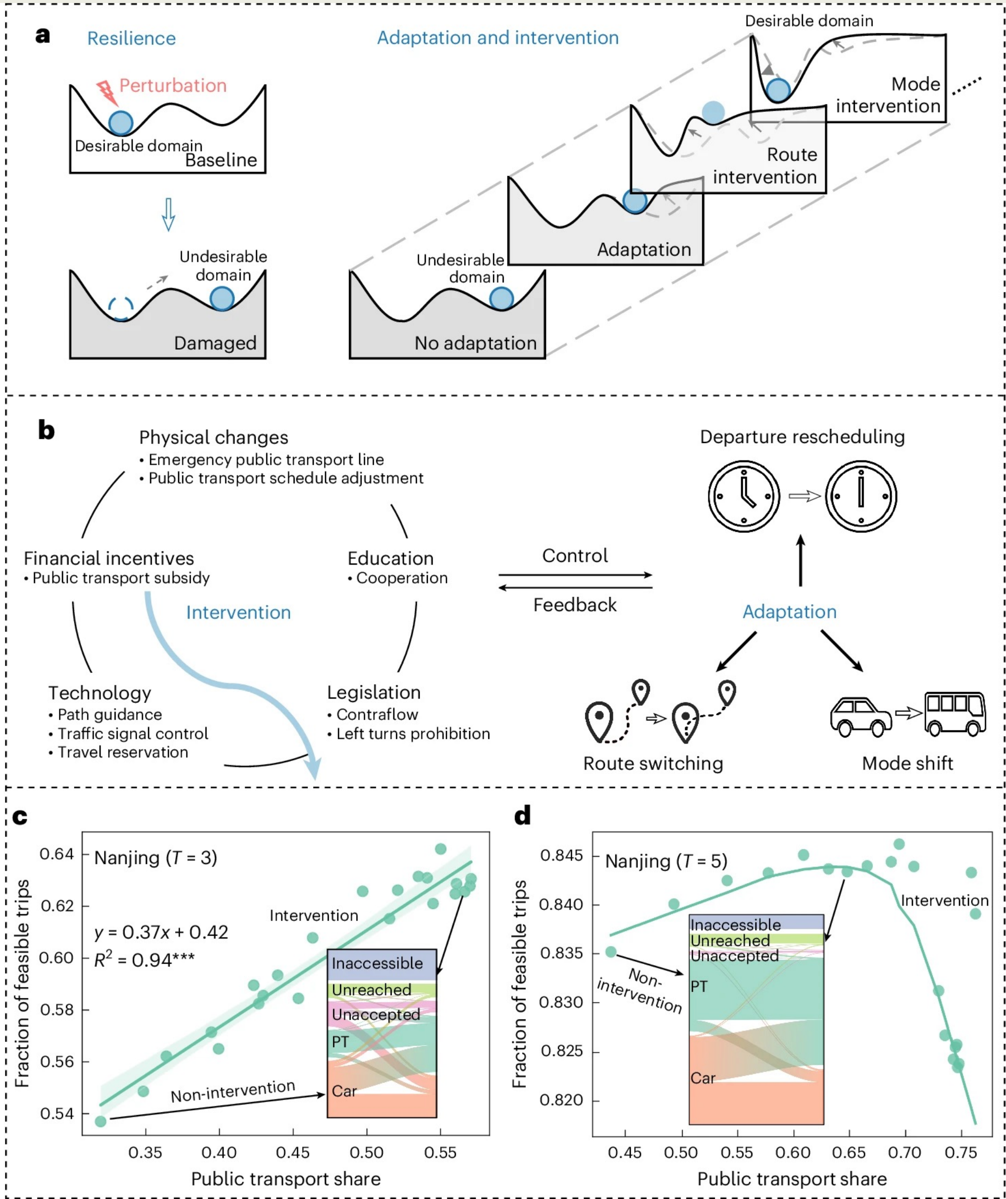
4. Applications to urban/sociotechnical systems

réf.: Li et al., 2025 ↓

- **Flood resilience of transport networks**
  - → Adaptive capacity for multimodal transport network resilience to extreme floods (Nanjing)
  - → Percolation analysis on multilayer network

[*https://www.nature.com/articles/s41893-025-01575-z*](https://www.nature.com/articles/s41893-025-01575-z)





Conclusion

- **Complex systems, networks and the social sciences: friends or foes?**
  - → Cybernetics (Norbert Wiener, 1948)
  - → General Systems Theory (Ludwig von Bertalanffy, 1968)
  - → The Network Society (Manuel Castells, 1996)
  - → Facets of Systems Science (George Klir, 2001)
  - → Sociology & Complexity Science (Brian Castellani, 2009)

- **How will you use systems/networks in your own work?**