






Sustainability Assessment of Urban Systems

(ENV-461) – BS 170

4: Key steps in SA: Systemic dimension

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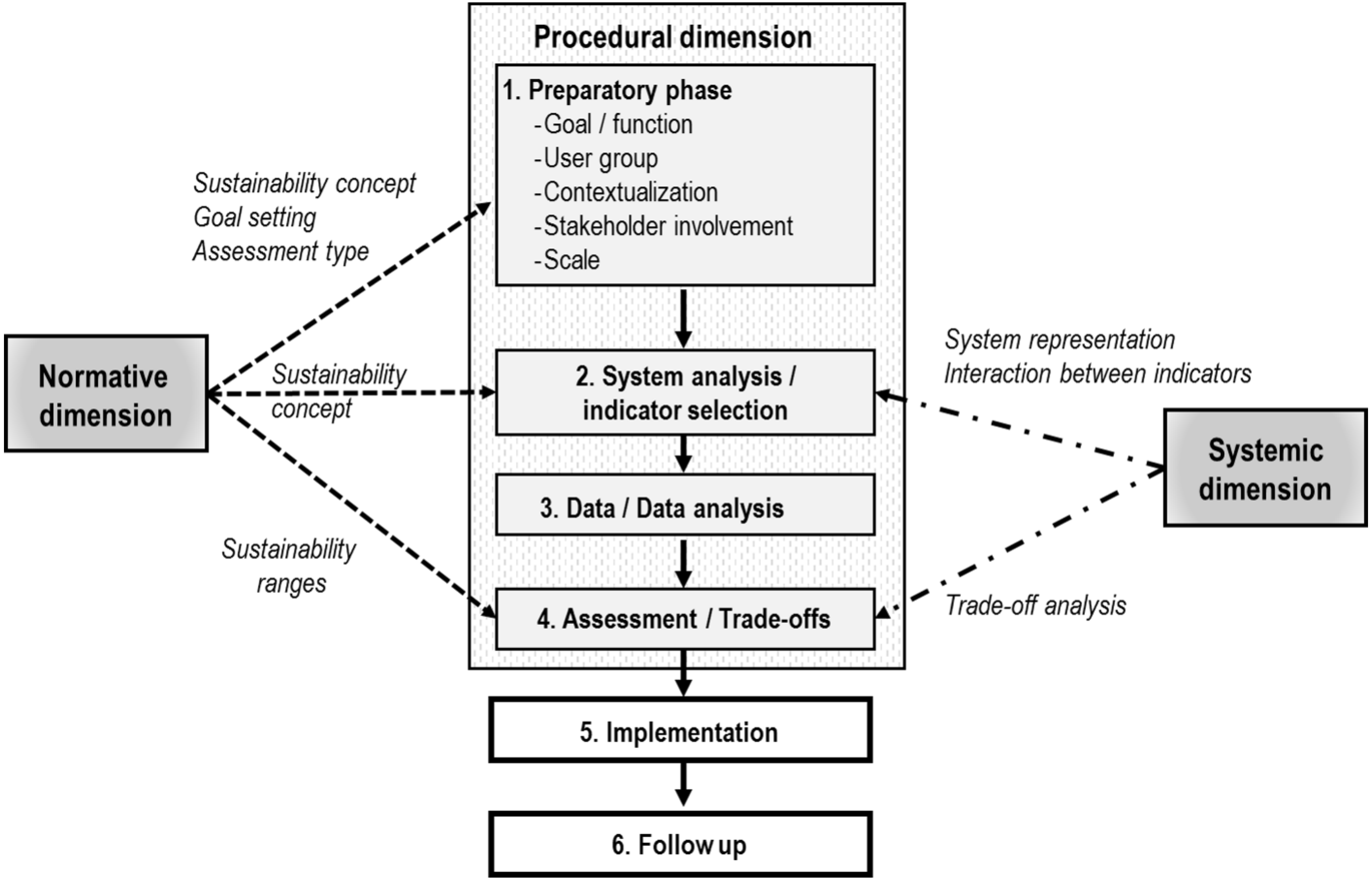
Laboratory on Human-Environment Relations in Urban Systems

Last week recap



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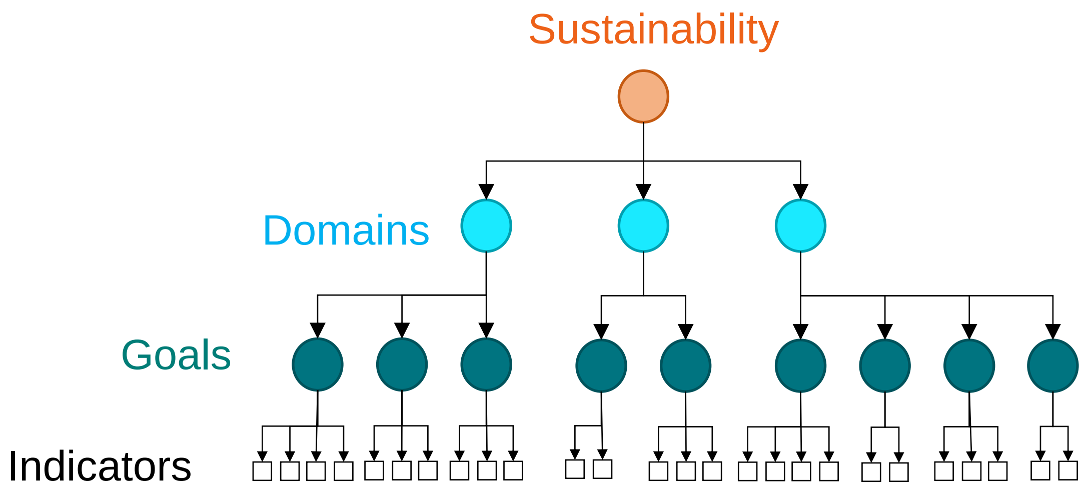
Last week recap

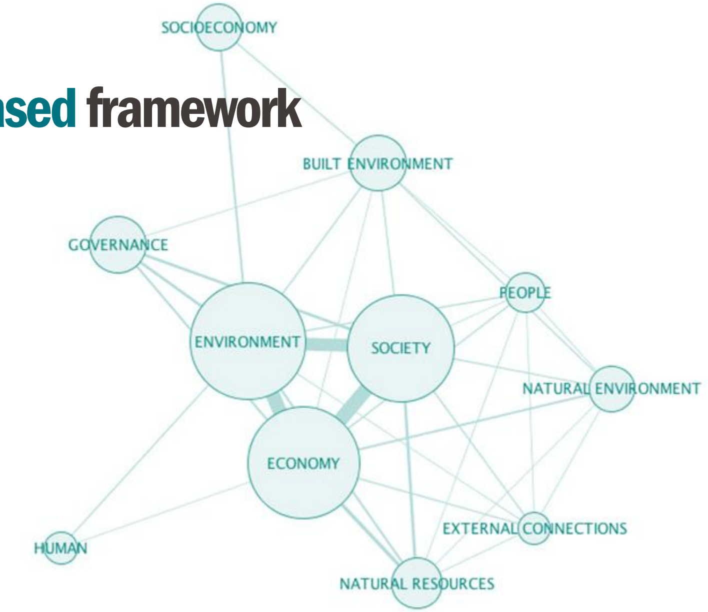
For *your* project

Hybrid framework

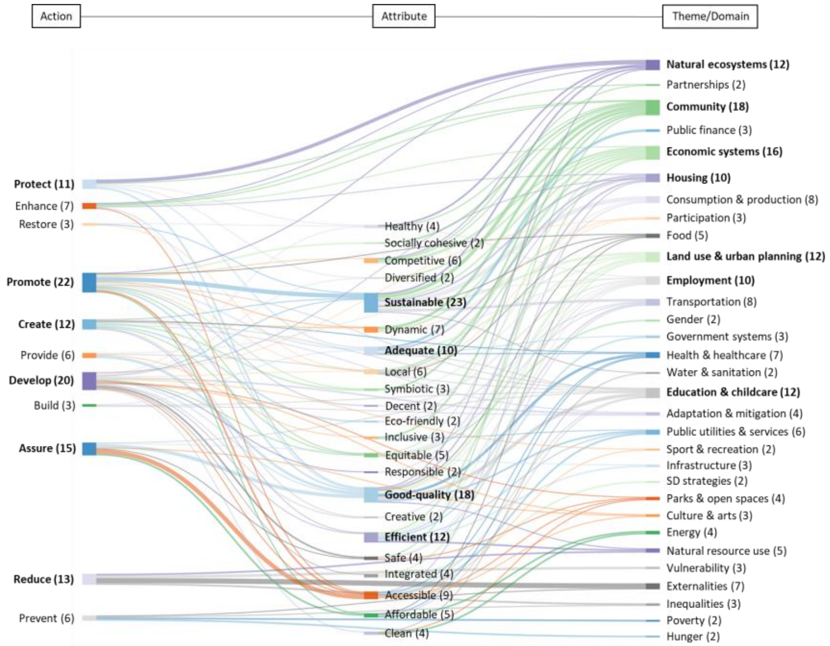


Hierarchization

Domain-based framework



Goal-based framework



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Program of the course

Lectures : BS 170 on Wednesdays, 13:15 – 16:00 (Lecture + Exercise)

n°	Date	Session	Milestones Project
1	19/02/2025	**Introduction** into sustainability and SA	
2	26/02/2025	**Sustainability issues** in **urban systems**	
3	05/03/2025	**Key steps in SA #1**: SSP, normative dimension, frameworks	**Groups formed**
4	12/03/2025	**Key steps in SA #2**: Systemic dimension	
5	19/03/2025	**Key steps in SA #3**: Participatory dimension	**Submission - Outline 19.03**
6	26/03/2025	**Deriving indicators (1/2)**	
7	02/04/2025	**Deriving indicators (2/2)**	
8	09/04/2025	**Influence matrix**	
9	16/04/2025	**Multi-Criteria Analysis**	
	23/04/2025	**Easter break**	
10	30/04/2025	**Deriving policy recommendations**	
11	07/05/2025	**Policy implications**	
12	14/05/2025	**Sustainability Assessment in practice**	
13	21/05/2025	**Exam**	
14	28/05/2025	**Presentation of semester work_2**	

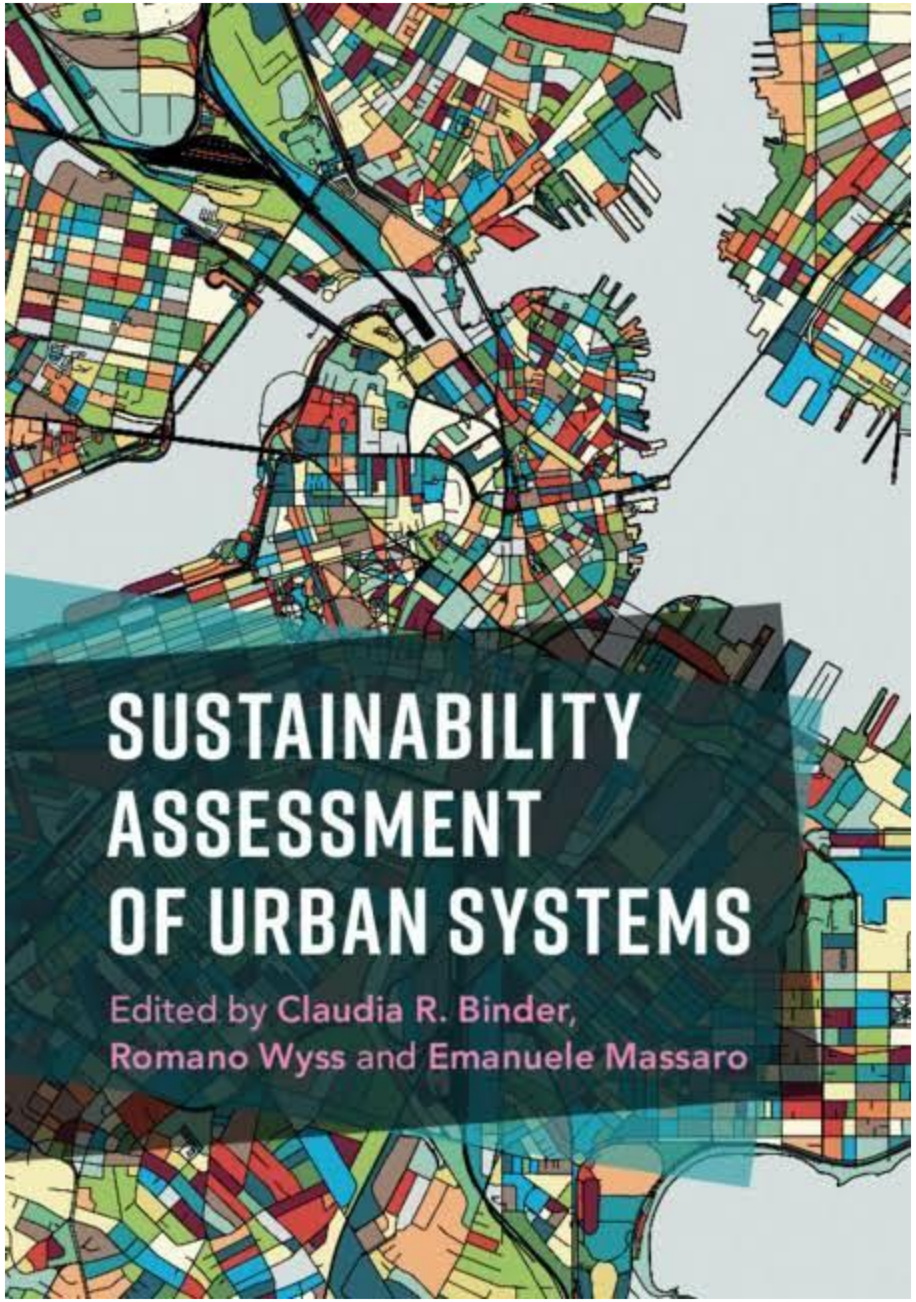
* May be updated depending on the number of students enrolled

Objectives

- Learn what is a **system and systems approach**?

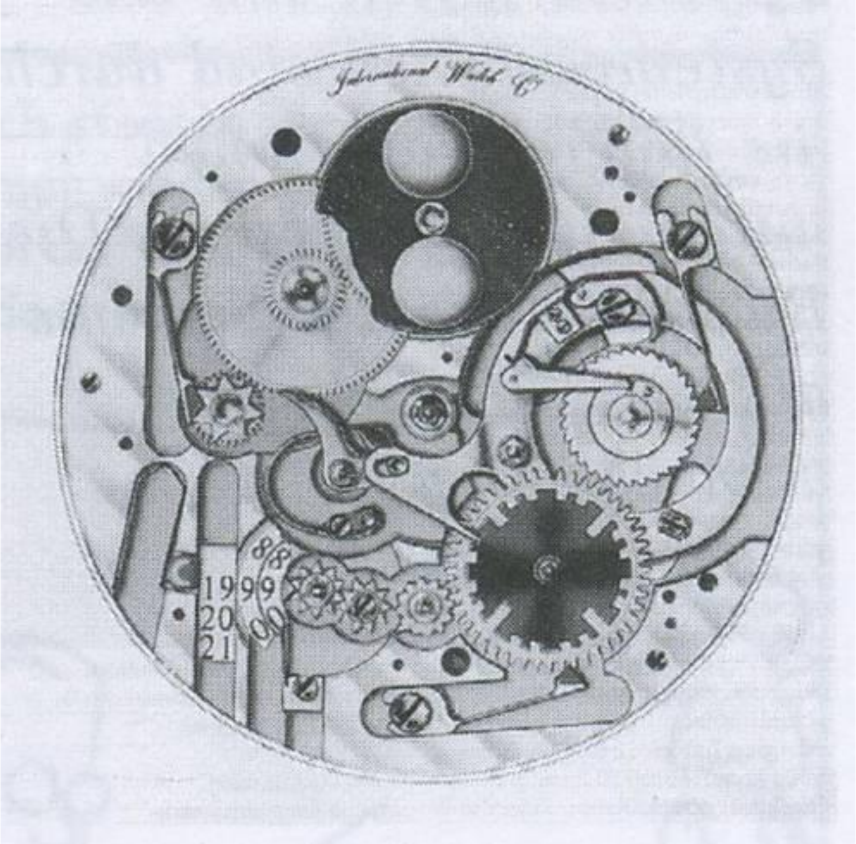
- Understand how a systems approach can inform **sustainability assessments**

Reading: Binder et al., **Systems Science and Sustainability Assessment** in Binder et al. (Eds), 2020. Sustainability Assessment of Urban Systems



System Science

Systems Science is an interdisciplinary field that studies the complexity of systems in nature, social or any other scientific field.

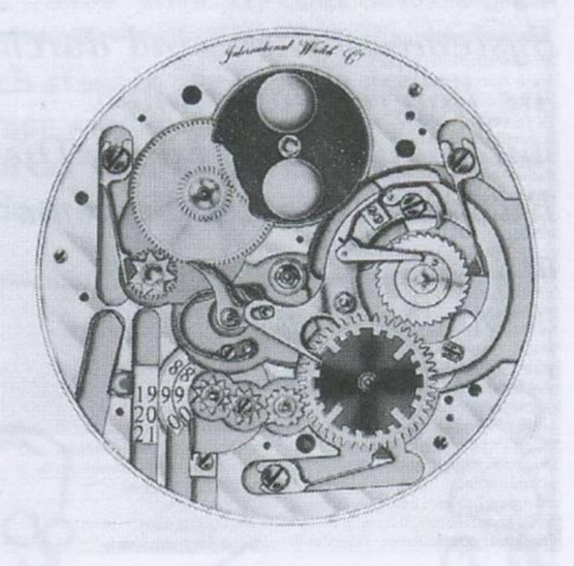


System sciences

System sciences focus on interrelations and feedbacks within systems

Goals:

- Understanding the dynamics of systems
- Insights into future developments / simulations
- Management approaches



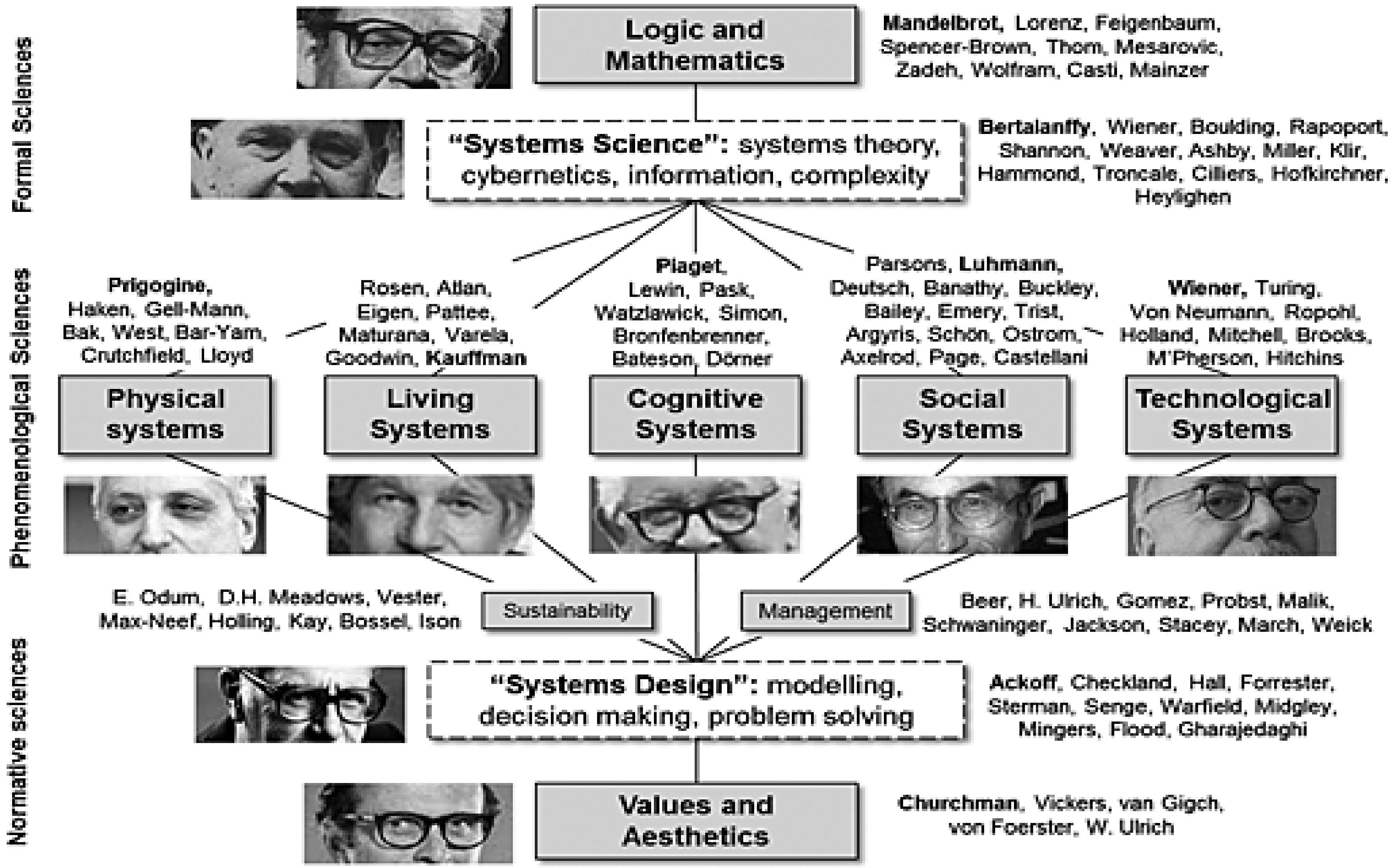
Imboden and Koch, 2003

Principle:

„The whole is more than the sum of its parts.“

Aristoteles (384-322 v. Chr.)

Overview of systems thinkers (Hieronymi, 2013)



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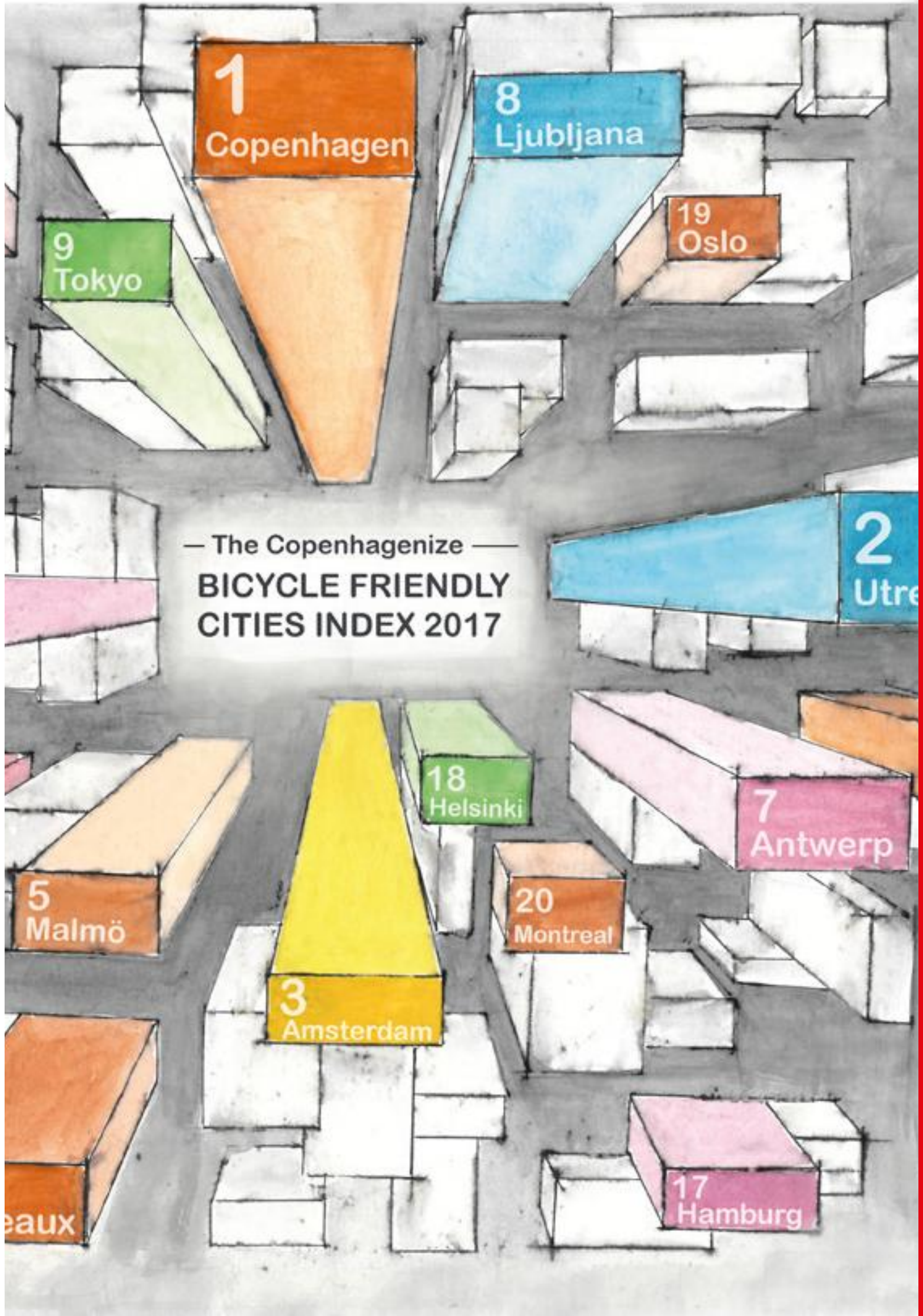
Axioms related to systems theory

Axiom	Definition (Adams et al., 2014)
1. Centrality Axiom	Central to all systems are two pairs of propositions: **emergence** and **hierarchy**, and **communication** and **control**
2. Contextual Axiom	System meaning is informed by the circumstances and factors that **surround the system**.
3. Goal Axiom	Systems achieve specific goals through **purposeful behavior** using pathways and means.
4. Operational Axiom	Systems must be **addressed in situ**, where the system is exhibiting purposeful behavior.
5. Viability Axiom	Key parameters in a system must be **controlled** to ensure continued existence.
6. Design Axiom	System design is a **purposeful imbalance of resources and relationships**. How a system is planned, realized and evolves
7. Information Axiom	Systems **create, possess, transfer, and modify information**.



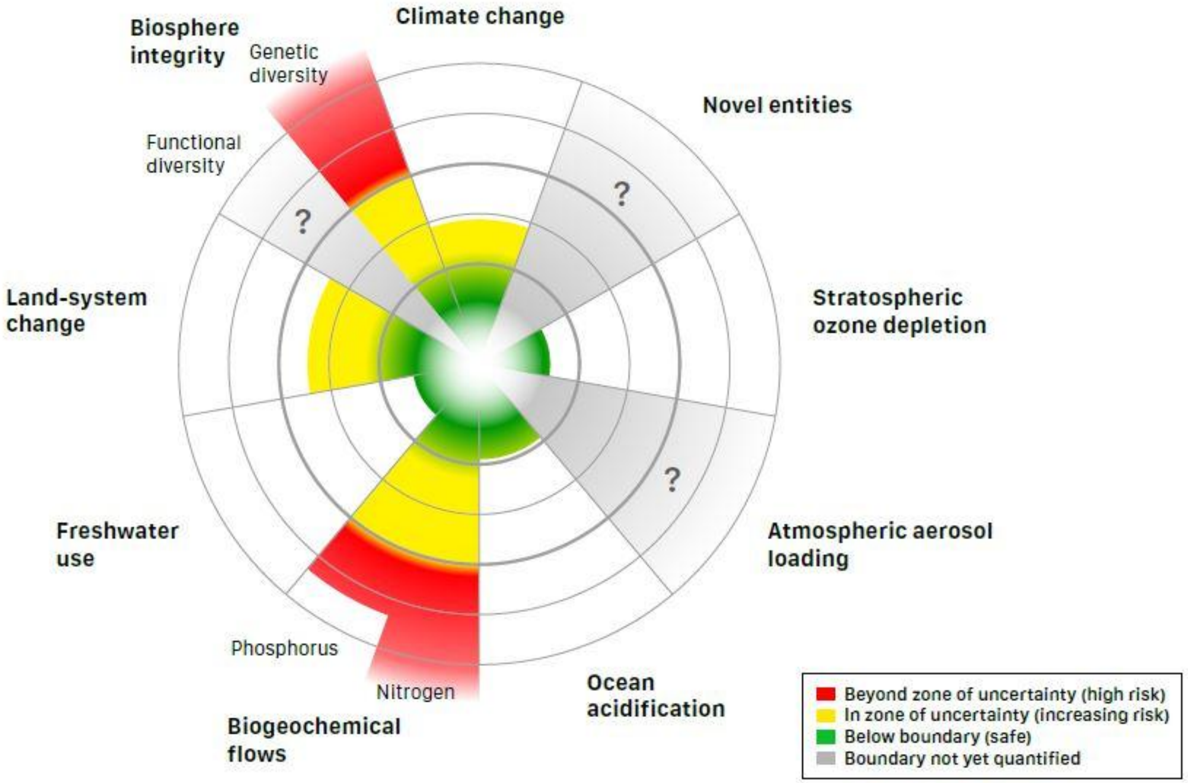
What is a systems approach?

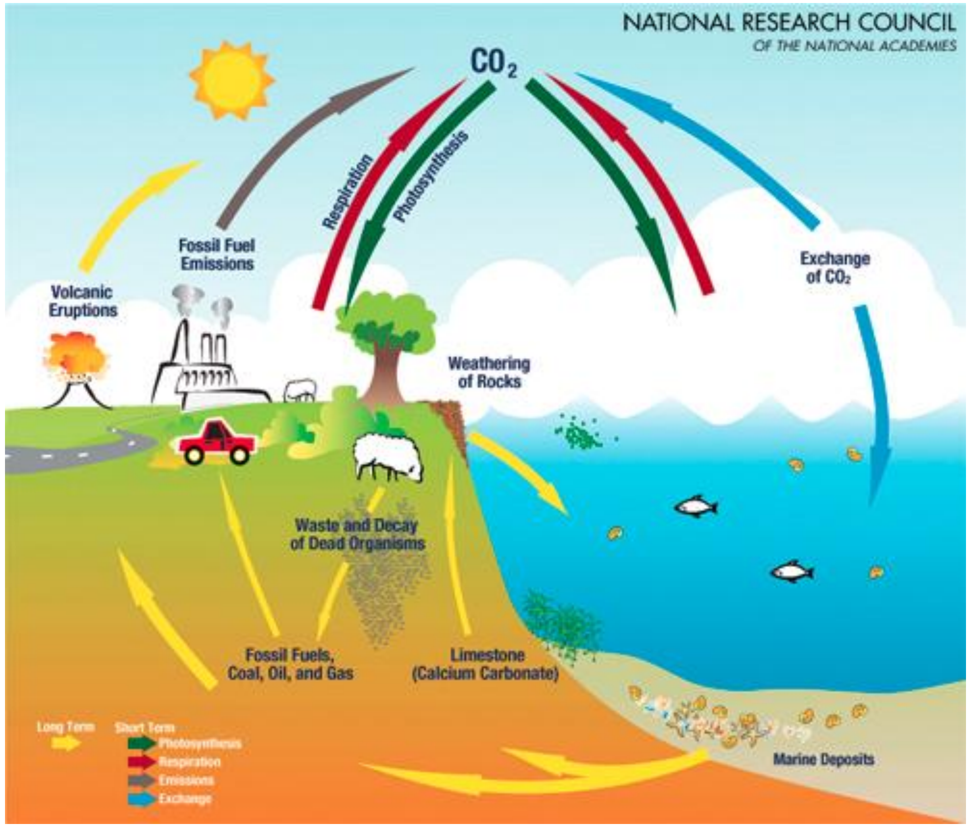
What is a systems approach?

- A systems approach is a tool for tackling complex problem, which involve
  - multiple issues (**elements of the system**) that are interdependent (**structure of the system**).
  - multiple and potentially conflicting values and worldviews (**goals** and **mental models**) that influence how people act (**structure of the system**) and thus affect the issues inherent the problem (**system state**).

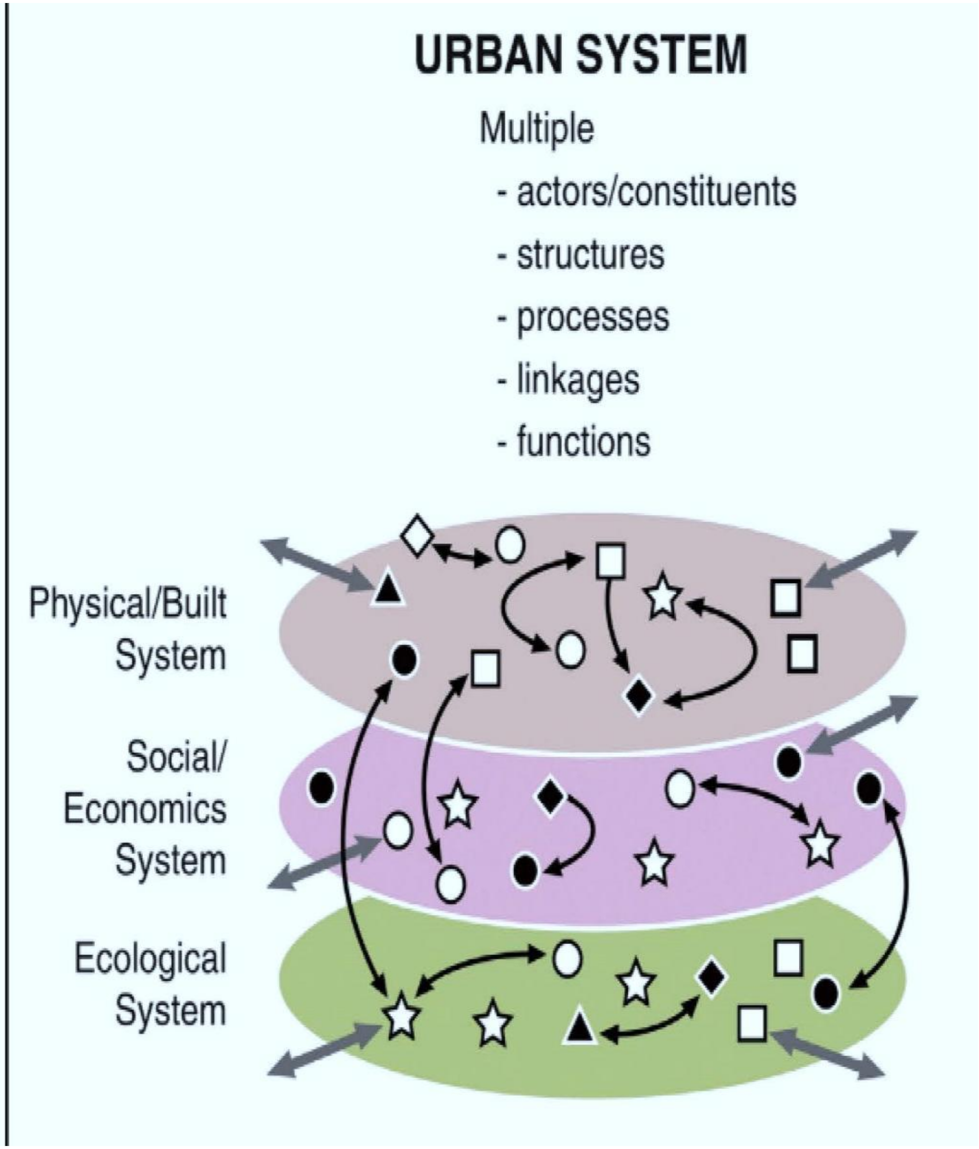
- A systems approach can be static or dynamic.
  - **Static**: Describe a system's state and compare it to the defined goal. The added value of the systems approach lies in the *holistic vision*.
  - **Dynamic**: Describe patterns in how a system's state evolves over time and compare it to the desired evolution. The added value of the systems approach lies in the holistic vision and in *finding explanations* for the observed patterns.

What is a systems approach?





Source: Steffen et al 2015, modified from Rockström et al 2009



What is a system?

What is a system?

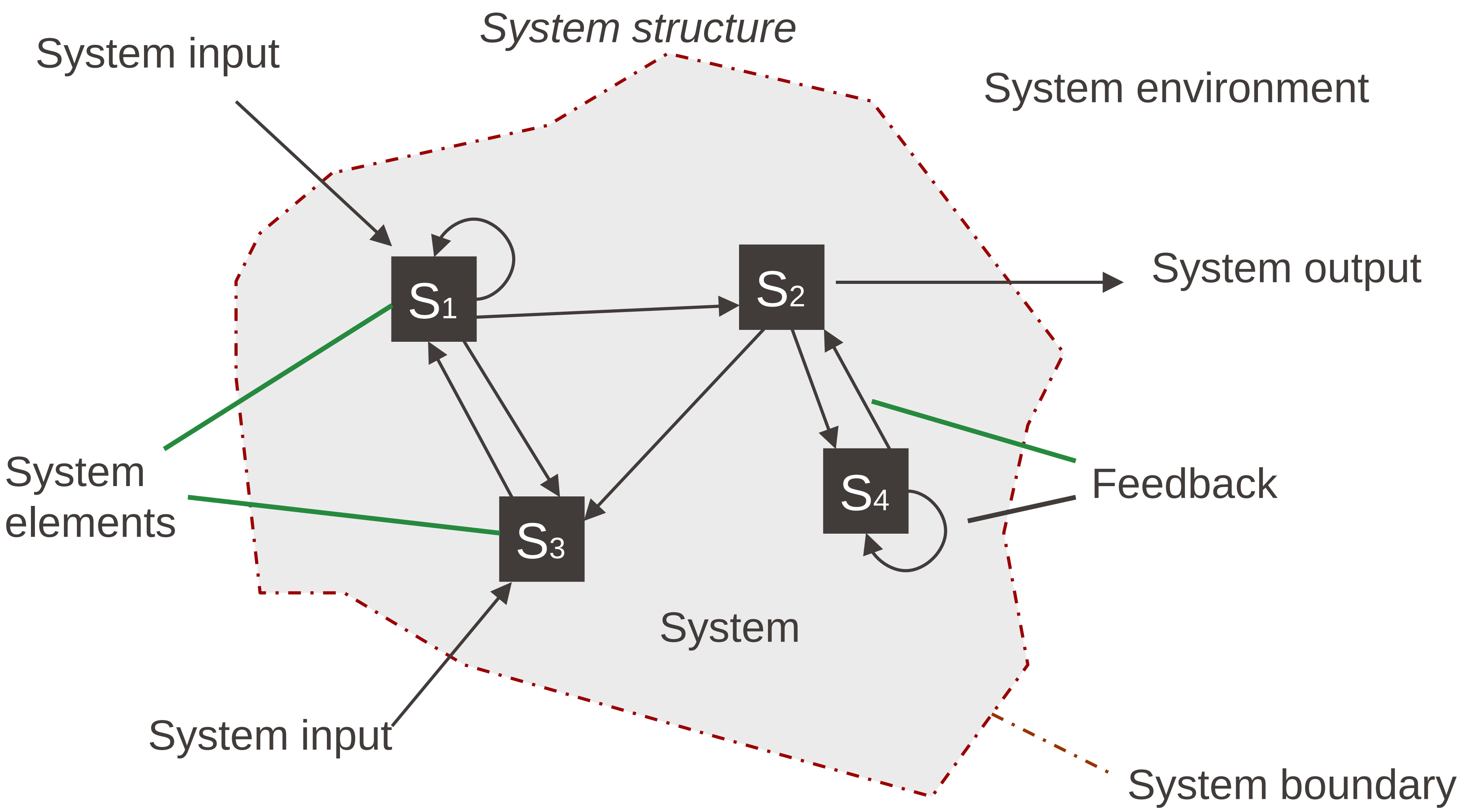
"A system is a set of things—people, cells, molecules, or whatever—interconnected in such a way that they produce their own pattern of behavior over time."

Meadows, 2009, p. 2

"A system is anything that is composed of system **elements** connected in a characteristic system **structure** […]. This configuration of system elements allows it to perform specific system **functions** in its system **environment**. These functions can be interpreted as serving a distinct system purpose. The system **boundary** is permeable for inputs from and outputs to the environment. It defines the system's identity and autonomy."

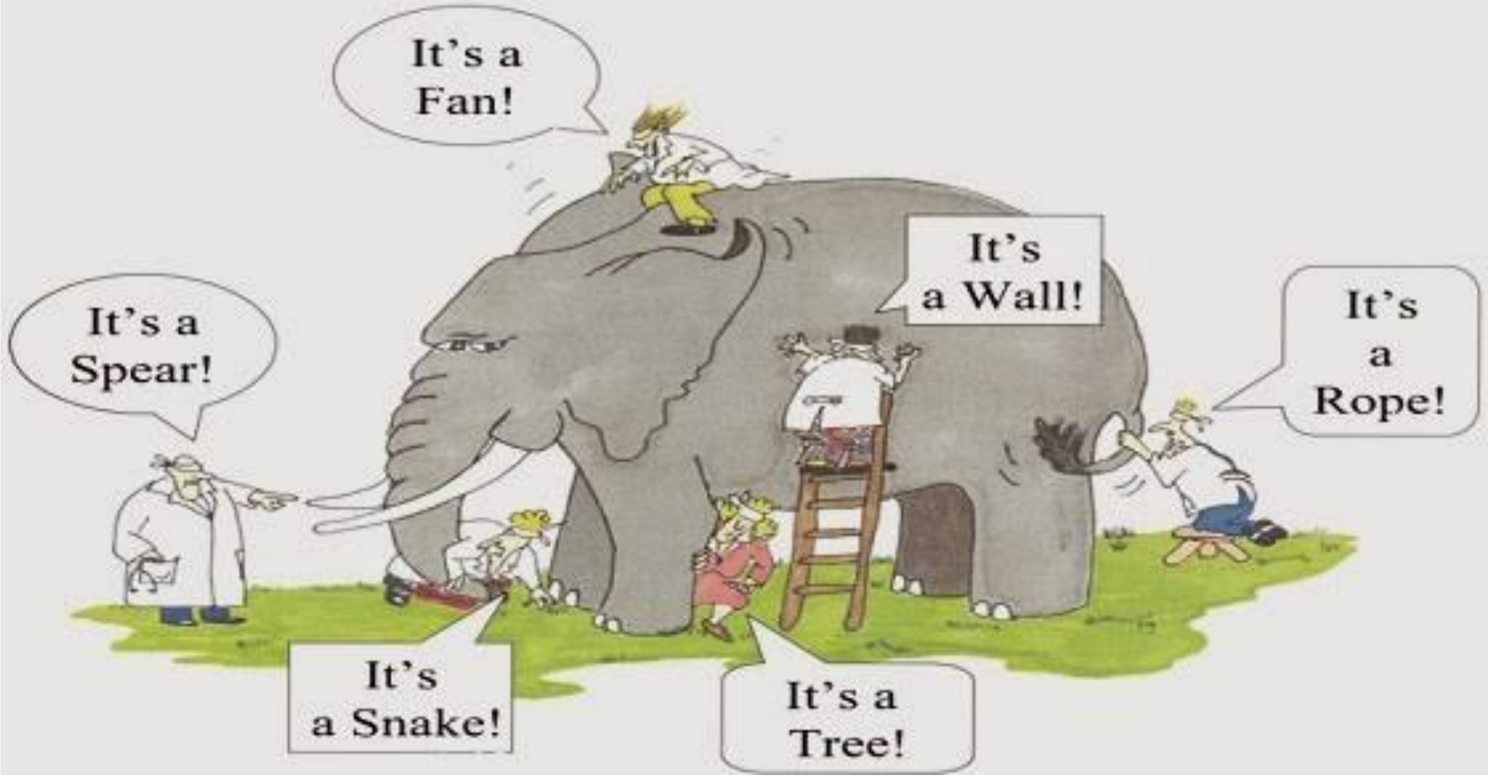
Bossel, H. (1999)

What is a system?



After Bossel, 2004; Mrotzek, 2009

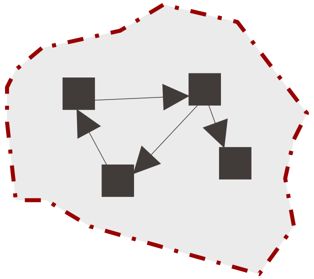
Systems structure



"The behavior of a system cannot be known just by knowing the elements of which the system is made."

The Blind Men and the Matter of the Elephant.
After Meadows (2008, p. 7) and adapted from Idries Shah (1970, p. 25)

Figure: https://medium.com/betterism/the-blind-men-and-the-elephant-596ec8a72a7d



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Key aspects for defining a system (I)

System characteristics and axioms		
System characteristics	**Description**	**Axioms**
1. System boundary, context, and environment	• Delimits the system in space and time, defines inputs and outputs. • Situates the system within its surroundings	Axiom (2)

1a. System boundary

- Defines what is inside of the system to be analysed and what belongs to the system context
- Defines inputs and outputs of the system
- Nested systems and hierarchy of systems (e.g. depending on the systems perspective, a systems element might become a subsystem
- Elements of a system boundary: space and time

Some authors include scope:

(i) which stakeholder have to be included;

(ii) what resources are available; and

(iii) what has to be included in the assessment itself.

1b. System context

- *Circumstances* are defined as “Particulars of the situation that define the **state of affairs**”
- *Factors* are “specific **characteristics or variables** that affect the situation”
- *Conditions* are “the prevailing state of the situation that influences outcomes” - **dynamics or changing system environments**.
- *Values* are defined as “**general beliefs** for which the system stakeholders have an emotional investment”
- *Patterns* relate to “a **perceived structure**, operation, or behaviour that is recurring - implicit rules present in the cultural surrounding of the system

Hester and Adams, 2017

How does the system context affect your sustainability assessment?
How does it affect the policy recommendations derived

Key aspects for defining a system (I)

System characteristics and axioms		
System characteristics	**Description**	**Axioms**
1. System boundary, context, and environment	• Delimits the system in space and time, defines inputs and outputs. • Situates the system within its surroundings	Axiom (2)
2. System purpose, goals, and decision-making	Goal and function of the system (e.g., self-preservation, conservation of a stable state, transformation to a new state). Includes design and decision-making processes and criteria across multiple goals.	Axiom (3) Axiom (1) Design Axiom (6)

2. System purpose – Functions of systems

- Self-preservation (biological and social systems)
- Conservation of a stable state (body temperature)
- Reproduction and multiplication (biol. und social systems)
- Security and shelter (ABS, airbag)
- Production (brewery → beer)
- Provision of housing
- Provision of services (health, communication, transport, etc.)
- Provision of „meaning“ (association)

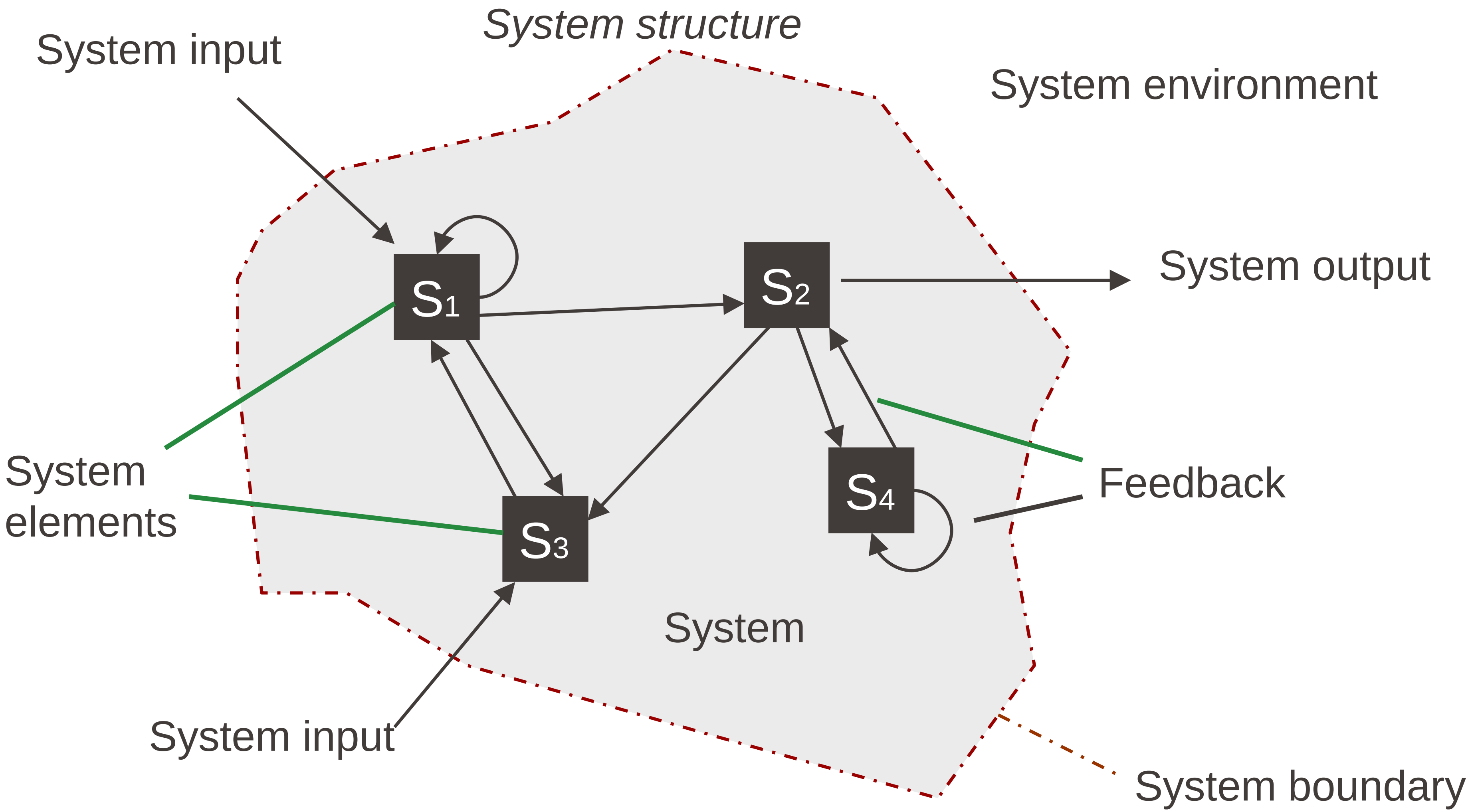
After Bossel 2004; Mrotzek, 2009, Ossimitz and Lapp, 2006

→ What is the purpose of a city?

Key aspects for defining a system (II)

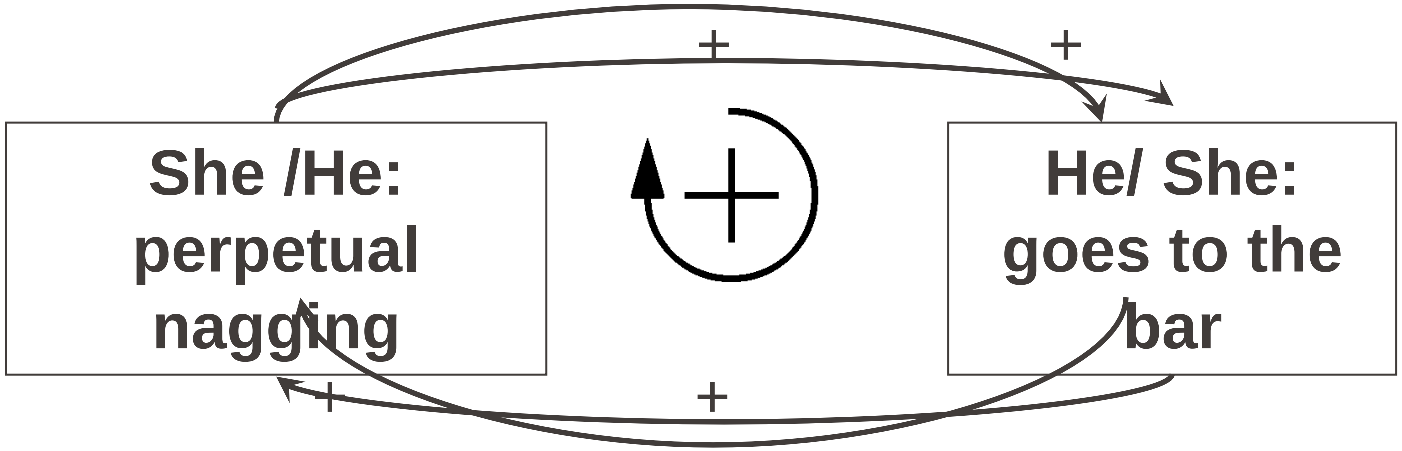
System characteristics and axioms		
System characteristics	**Description**	**Axioms**
3. System structure and dynamics	Refers to **elements**, **processes**, and their **interrelations**: e.g., • hierarchy and subsystems • system elements • interrelation between system elements (feedbacks) • emergence, adaptability of a system	Centrality Axiom (1) Operational Axiom (4) Viability Axiom (5) Design Axiom (6)

What is a system? → What are the elements in your city?



After Bossel, 2004; Mrotzek, 2009

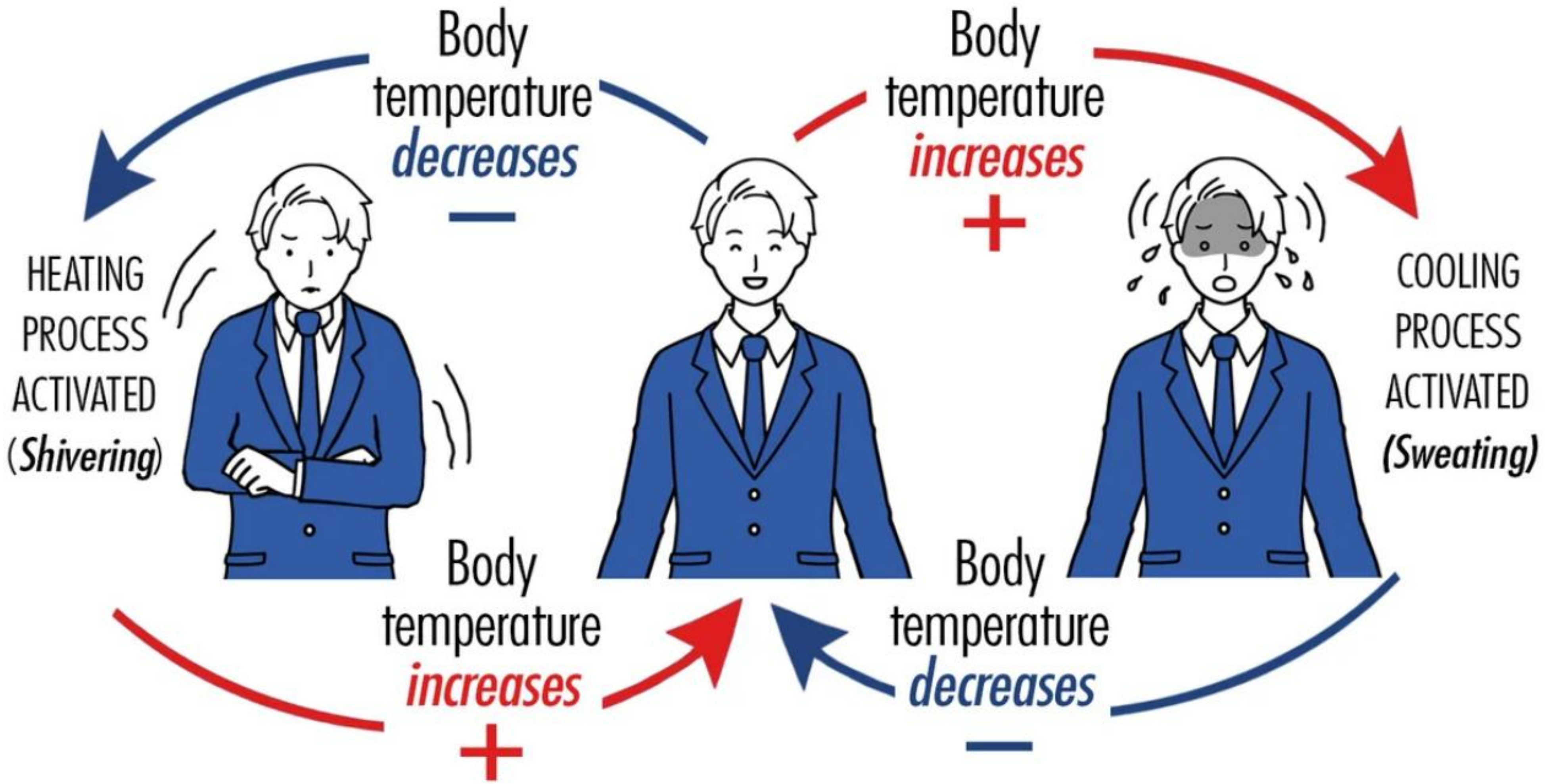
System dynamics - The arguing couple (after P. Watzlawick)



She / He: „I nag, because you go to the bar constantly!“
He / She: „I go to the bar constantly, because you nag all the time!“

Systemic: escalating feedback!

System structure determines system dynamics



Source: mari_matayosh / iStock / Getty Images Plus

Key aspects for defining a system (II)

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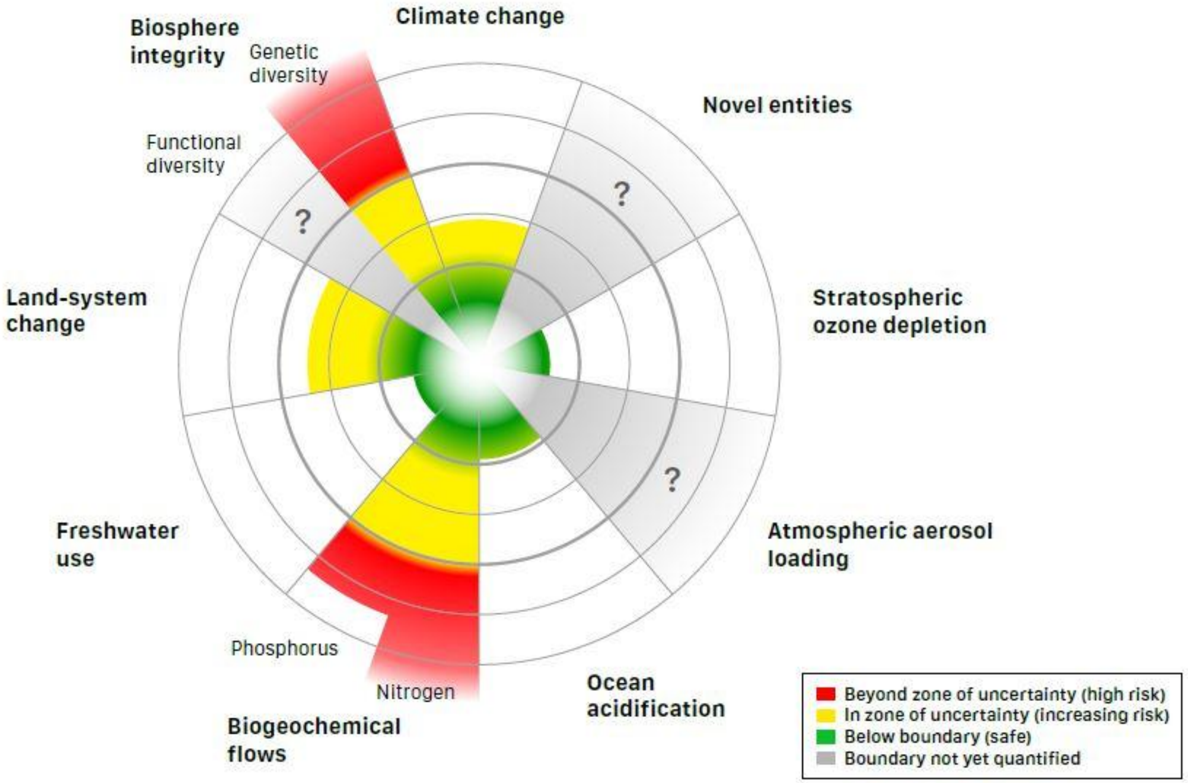
3. System structure and dynamics	Refers to **elements**, **processes**, and their **interrelations**: e.g., • hierarchy and subsystems • system elements • interrelation between system elements (feedbacks) • emergence, adaptability of a system	Centrality Axiom (1) Operational Axiom (4) Viability Axiom (5) Design Axiom (6)
4. System information, monitoring, and learning	Refers to how a system can be **monitored**, and which variables and parameters have to be measured **to assure progress** towards sustainability, including indicators. These inform both ex-ante and ex-post sustainability assessments.	Centrality Axiom (1) Information Axiom (7)

What do we monitor? - Indicators



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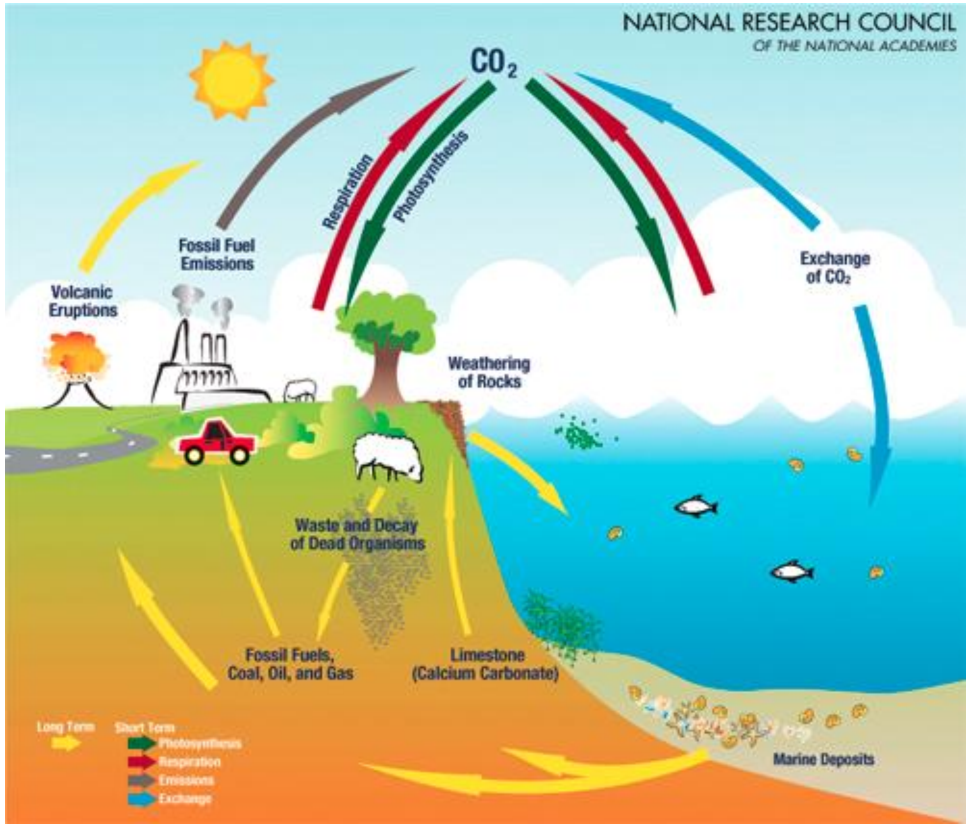
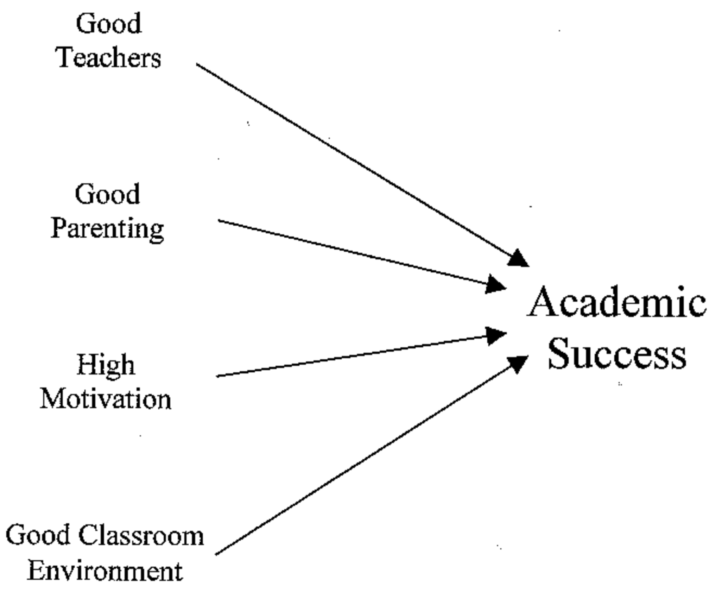
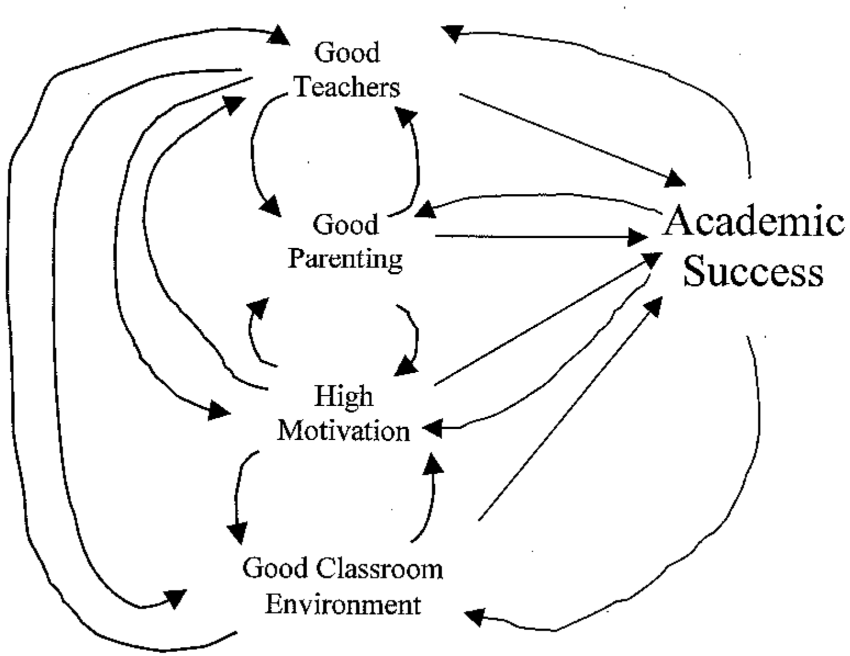


Why is a system view useful?

Why is a systems view useful?



Descriptive View



Explanatory System View

Source: Richmond, 2001

30

Systems tool

Causal Loop Diagram

Causal Loop Diagrams (CLDs)

- depict **causal relations** in systems
- help **revealing feedback** in systems
- are used to **communicate** complex system structures

CLDs instructions

- The arrows in a causal loop diagram are label + or – depending on whether the causal influence is positive or negative!

- Two variables change in the **same direction**: positive polarity

Number of Births —(+)→ Population

- Two variables change in the **opposite direction**: negative polarity

Number of fatalities —(-)→ Population

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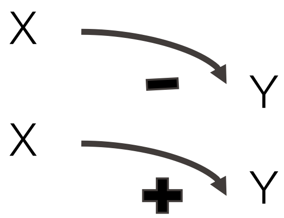
Causal Loop Diagrams



When X increases, Y decreases

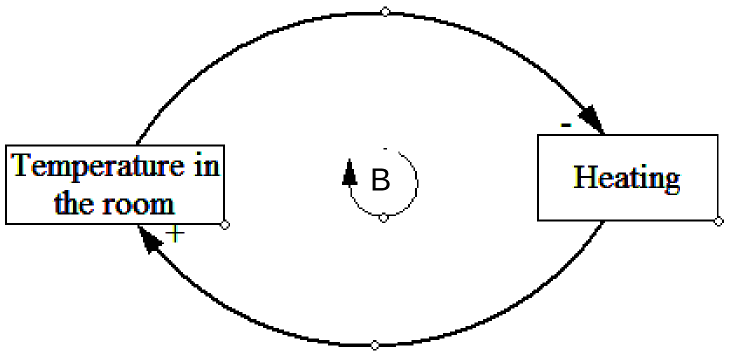
When X increases, Y increases

Positive Feedback (escalating / reinforcing feedback):
Feedback is positive, if a loop consists of causalities with positive polarity only or an even number of negative polarities

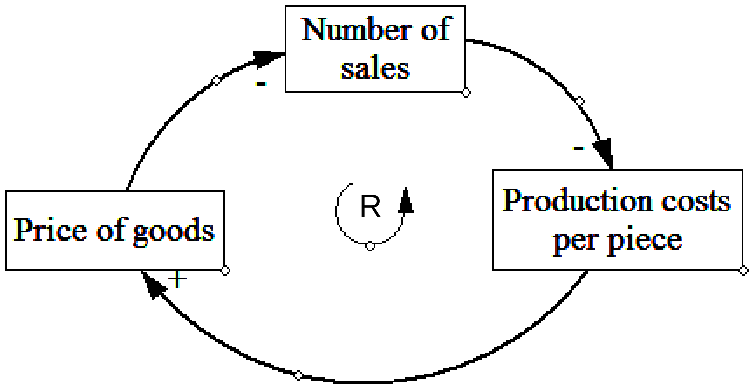
Negative Feedback (balancing feedback):
Feedback is negative, if a loop consist of an uneven number of negative causal relations.

→ Terms “positive” and “negative” might be misleading since they do not necessarily imply an increase or a decrease of systemic processes

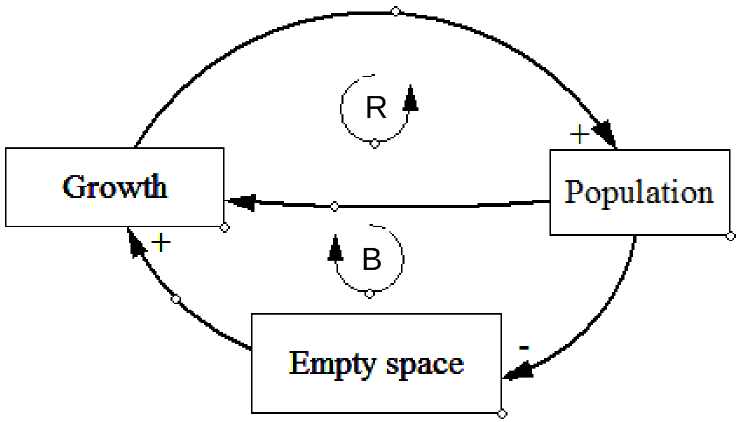
Examples of causal feedback loops



Stabilizing / Balancing feedback loop



Escalating / Reinforcing feedback loop



Two feedback loops

System dynamics – builds on system structure

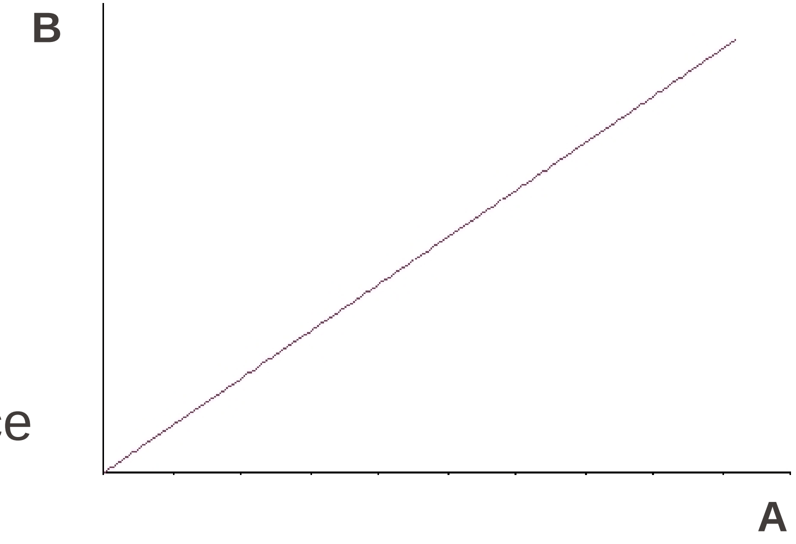
- Structure of a system determines its dynamics
- Key: **escalating or stabilising feedbacks**
- Potential dynamics:
  - Stabilising
  - Oscillation
  - Time delay
  - Chaotic change
  - Escalation
  - Overshoot and collapse

System dynamics (II) - linear systems

- Linear system are special cases
- Characteristics
  - Double cause leads to double effect
  - Combined effect of multiple causes equals the sume of the single causes
- Example: Paying in the supermarket
  - 1. Two products cost double the price
  - 2. Order of payment is not relevant
- In linear systems usually „the“ solution exists for „the“ problem
- Very rare outside mathematics

System behavior: Linear systems

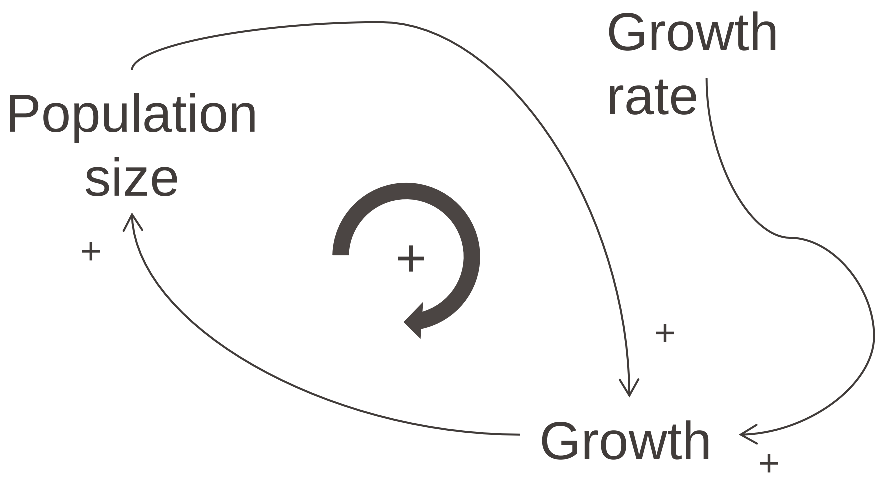
- Very seldomly observed in reality
- Growth is constant



Examples:

- Growth of railway network
  - $y = L_0 + l \cdot x$
- Shopping: two products are twice the price of one
  - $y = p \cdot x$

System behavior: Exponential growth



Positive Feedback is expected to cause **exponential growth**.

Positive feedback is often cause of **undesirable phenomena**:

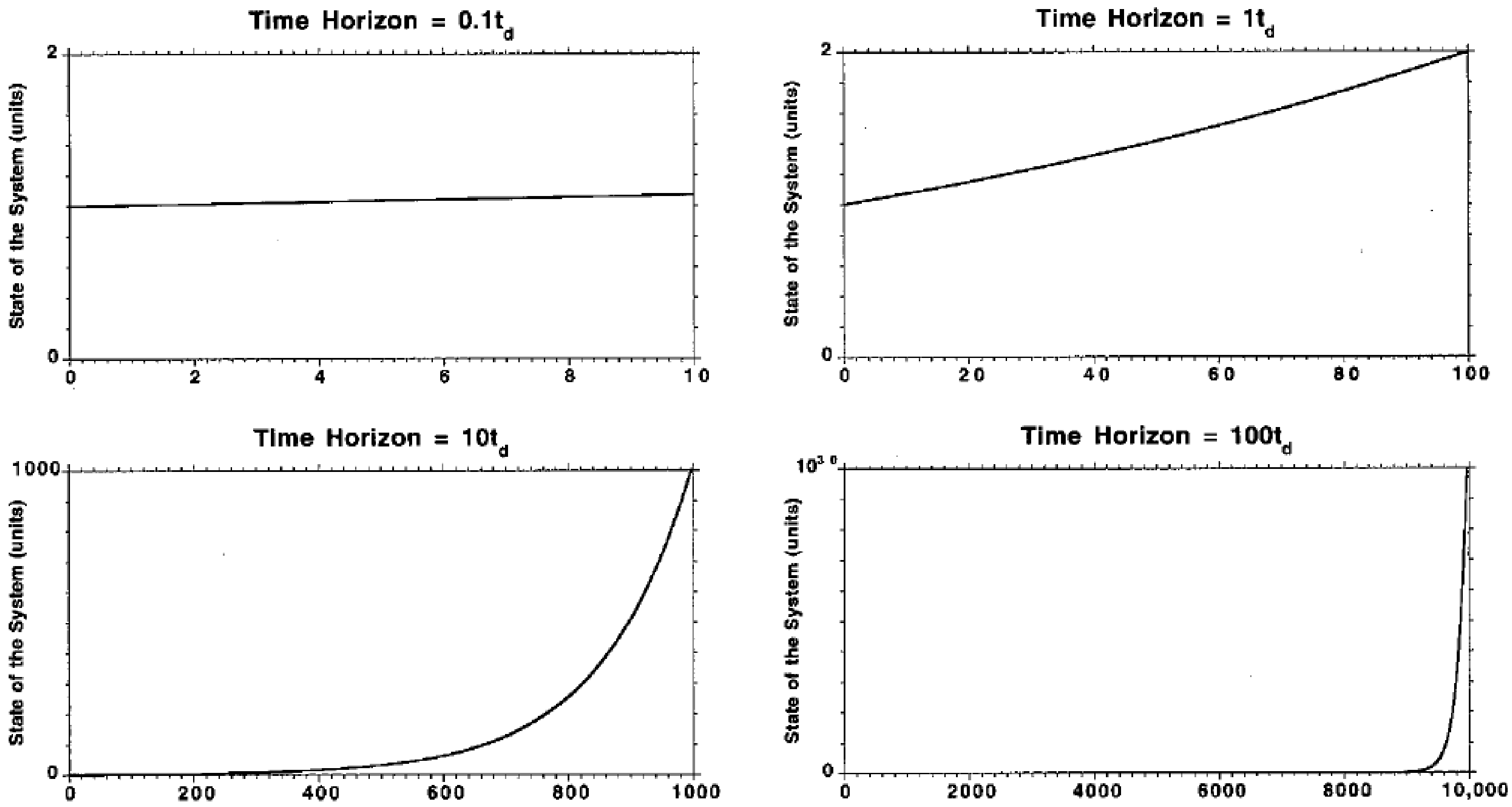
→ Rapid population growth
→ Industrial production and pollution
→ Thawing of the arctic ice sheet

The system doubles in size in the same interval of time → **doubling time**

System behavior: Linear or exponential?

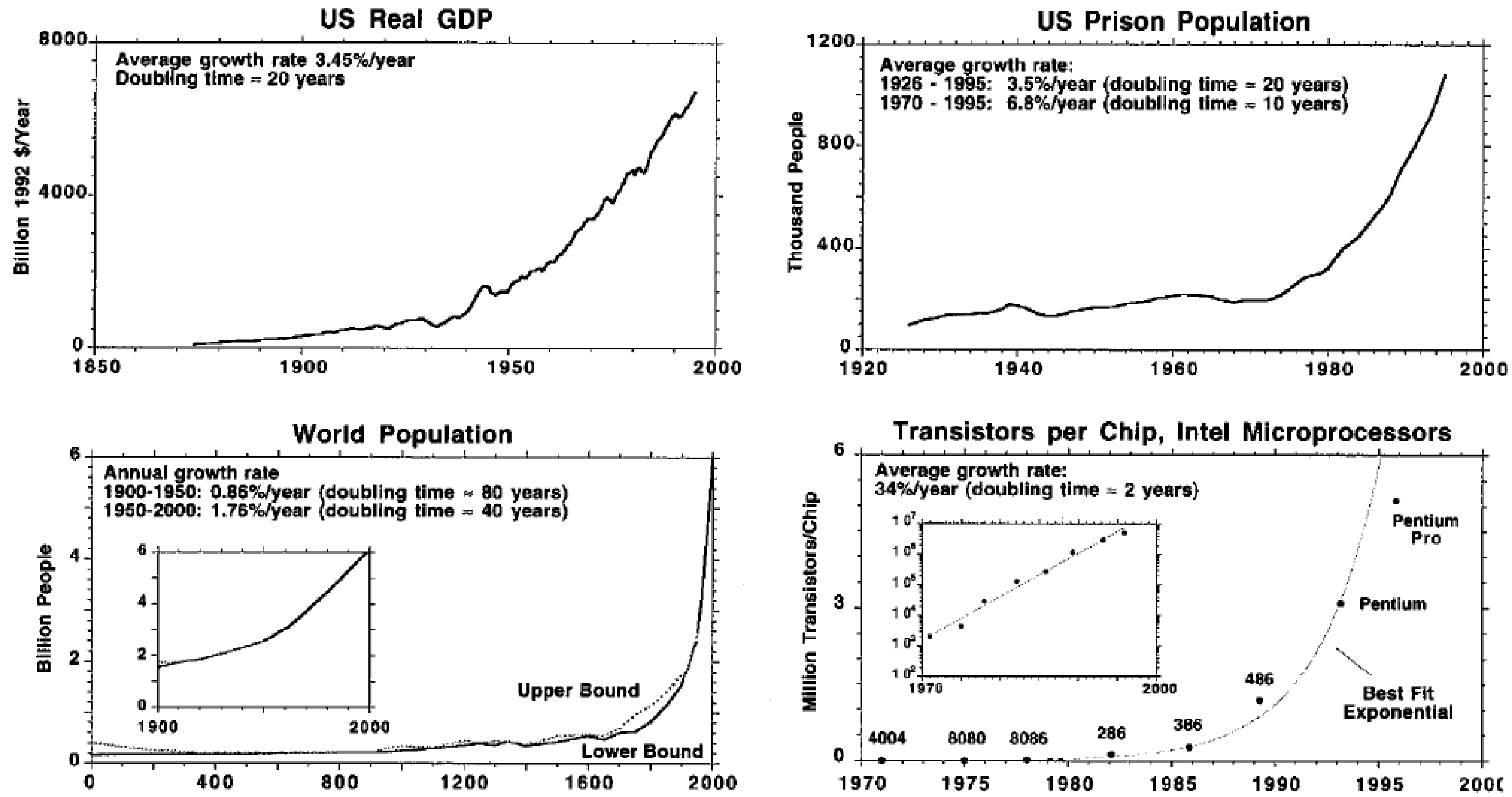
FIGURE 8-5 Exponential growth over different time horizons

The state of the system is given by the same growth rate of 0.7%/time period in all cases (doubling time = 100 time periods).



(Sterman, 2000)

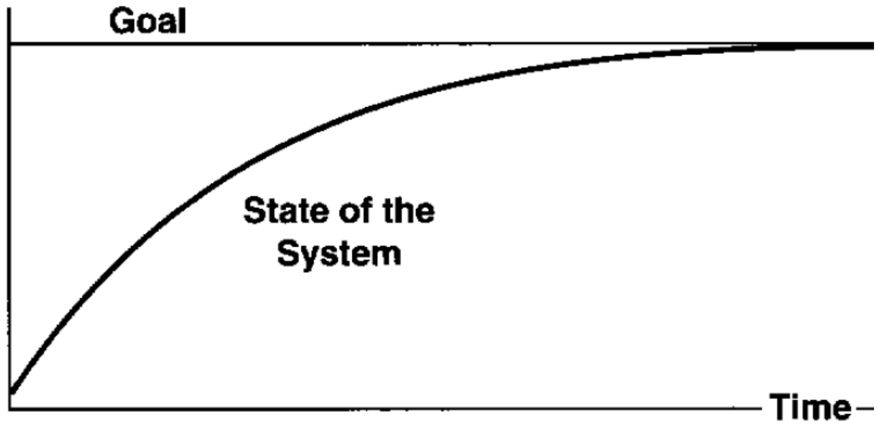
System behavior: Ex. exponential growth



Sources: Real GNP: Prior to 1929, Historical Statistics of the US. Real GDP, 1929-present: Survey of Current Business, Bureau of Economic Analysis. State and Federal Adult Prison Population: 1926-1970, Historical Statistics of the US; 1970-1980, Kurian (1994); 1980-1995, US Dept. of Justice. World Population: Prior to 1950, US Census Bureau summary of various estimates; 1950-present, US Census Bureau. Inset shows 1900-1996. Microprocessor performance: Joglekar (1996). Curve is best fit exponential function. Inset shows performance on semi-log scale.

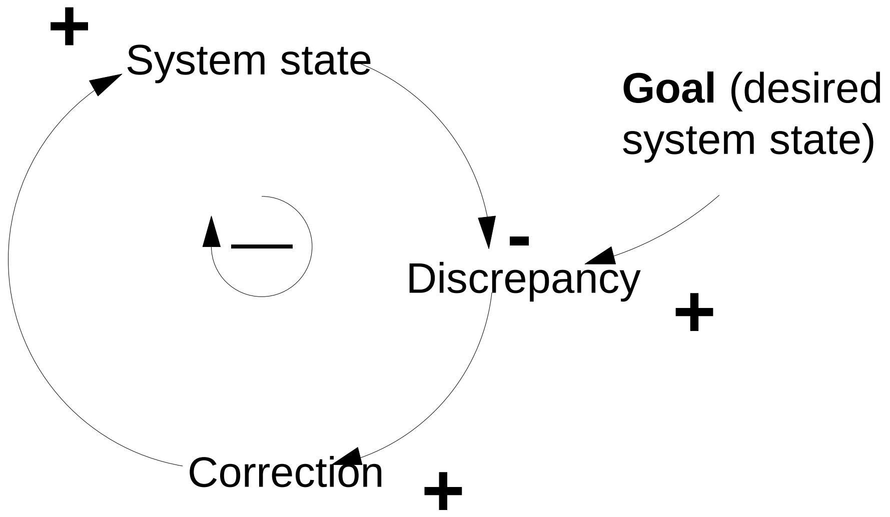
(Sterman, 2000)

System behavior: Goal-oriented „growth“

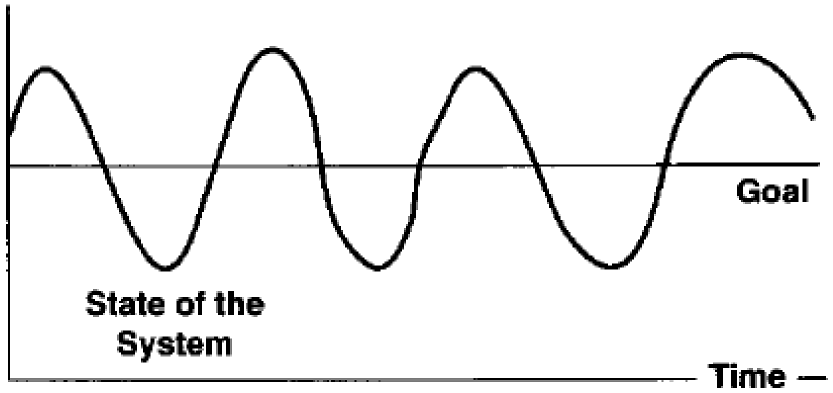


(Sterman, 2000)

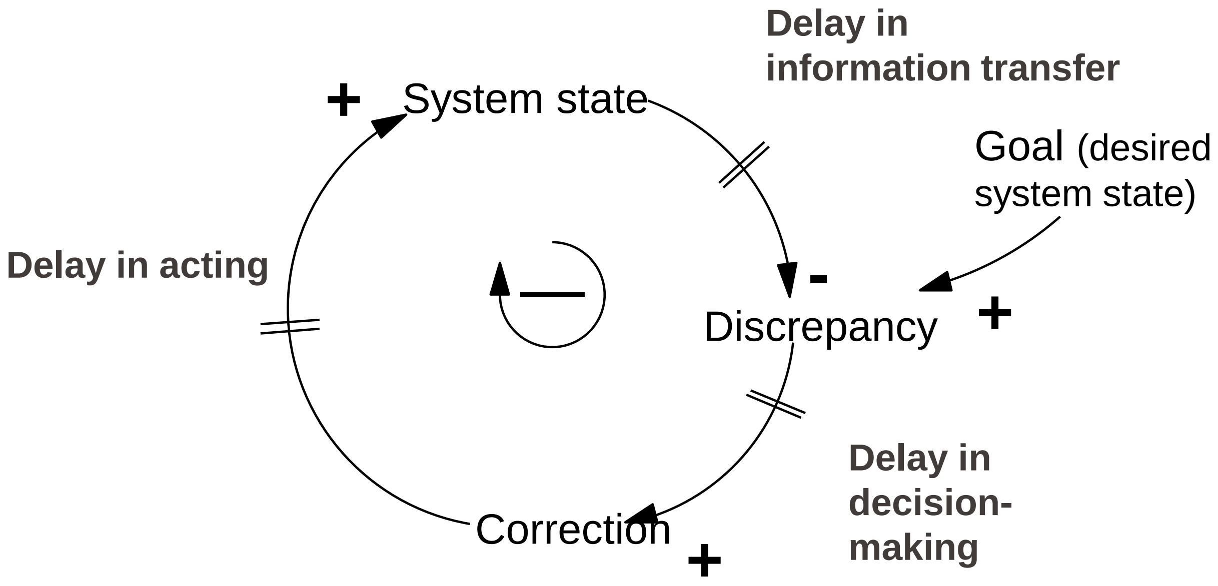
Goal seeking growth based on negative feedback!



System behavior: Oscillating dynamics

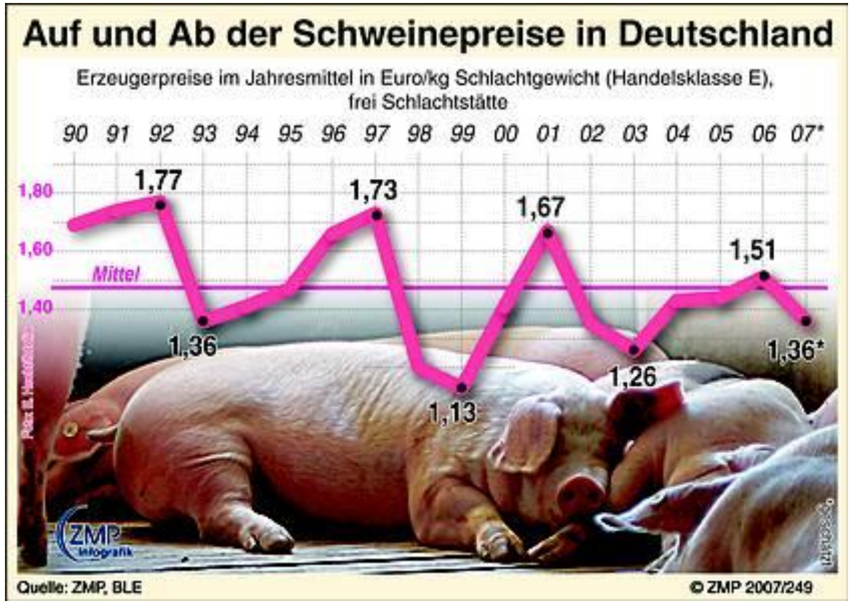


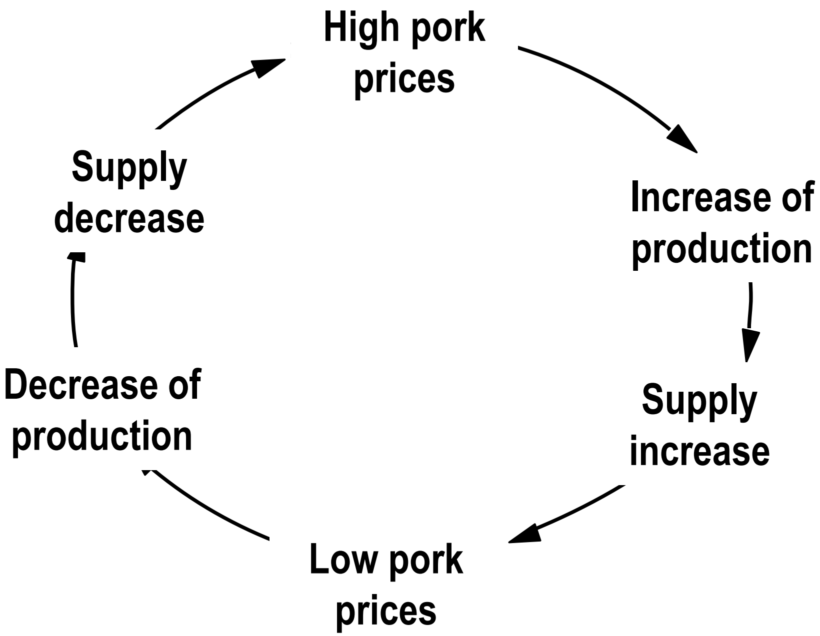
(Sterman, 2000)



Where have you experienced these types of behavior?

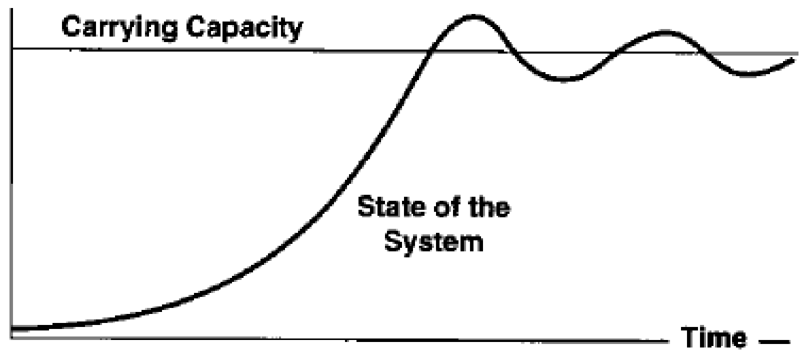
System behavior: Ex. oscillating dynamics





- Delayed response of producers to overproduction → collapse of prices
- Oscillation is also observed in other markets
- Further examples: shortage/excess of teachers / 5 years delay due training periods

System behavior: Sigmoidal growth and oscillation



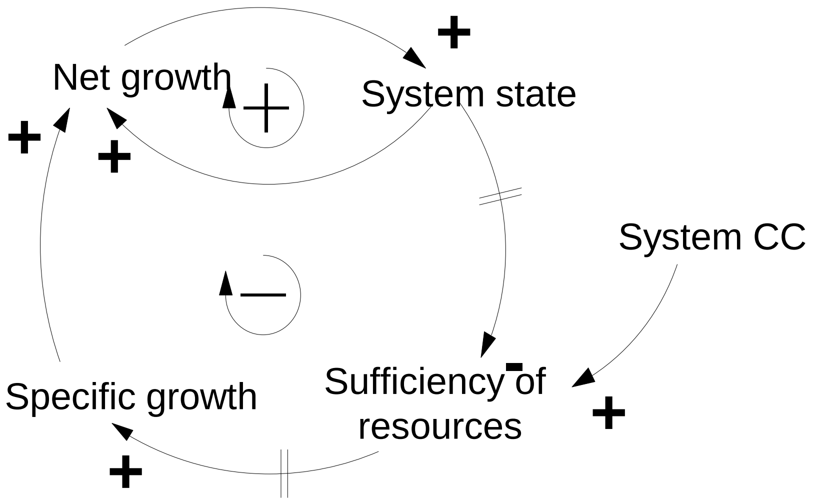
(Sterman, 2000)

ΔS/Δt

Absolut growth

ΔS/SΔt

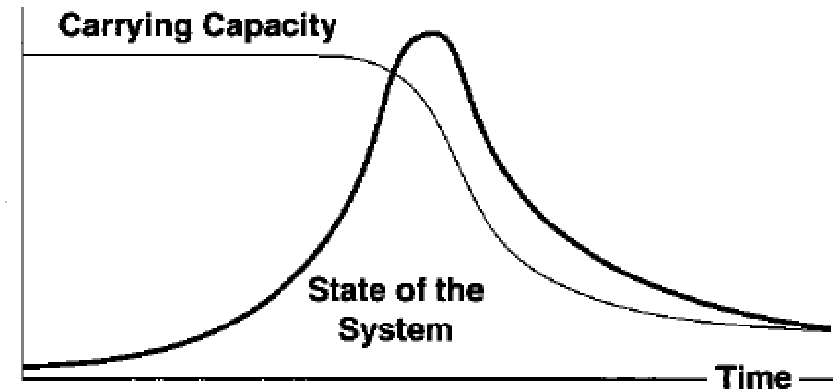
Increase per capita

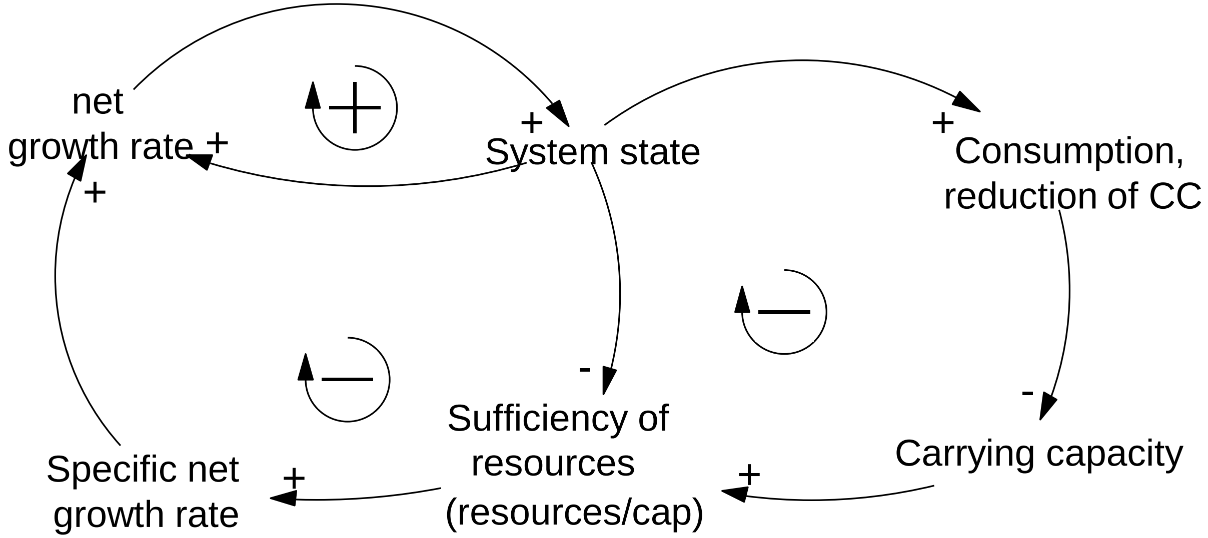


Sigmoidal growth and oscillation

1. Initially system is growing without restrictions (pos. feedback) → exponential growth
2. Negative feedback is time delayed → system is growing beyond CC
3. Once neg. feedback kicks in system is shrinking as resources are too low (above CC)
4. System retreats below CC as neg. feedback is delayed → oscillation

System behavior: Overshoot and collapse





Overshoot and collapse

Carrying capacity (CC) is affected by system state.

→ Overuse (e.g. consumption of non-renewable resources)
→ Renewal of system's CC is hindered
→ Human-environmental systems are prone to this type of behavior (e.g. overfishing, overgrazing)

(Sterman, 2000)

System dynamics – builds on system structure

- **Which type of dynamics would you expect in your cities?**
- Key: **escalating or stabilising feedbacks**
- Potential dynamics:
  - Stabilising
  - Oscillation
  - Time delay
  - Chaotic change
  - Escalation
  - Overshoot and collapse

How can a systems approach enhance a SA?

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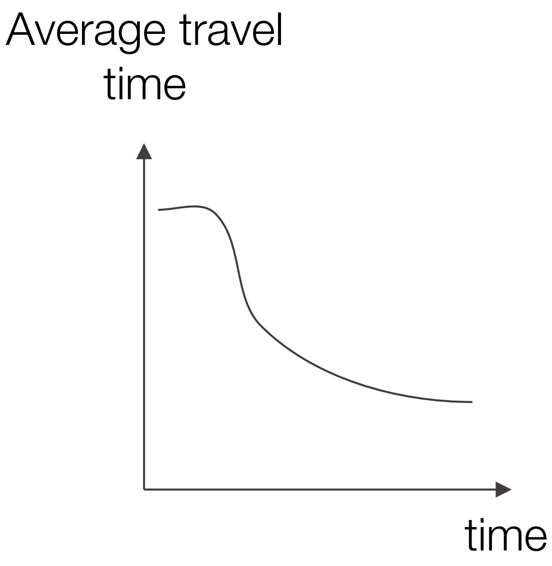
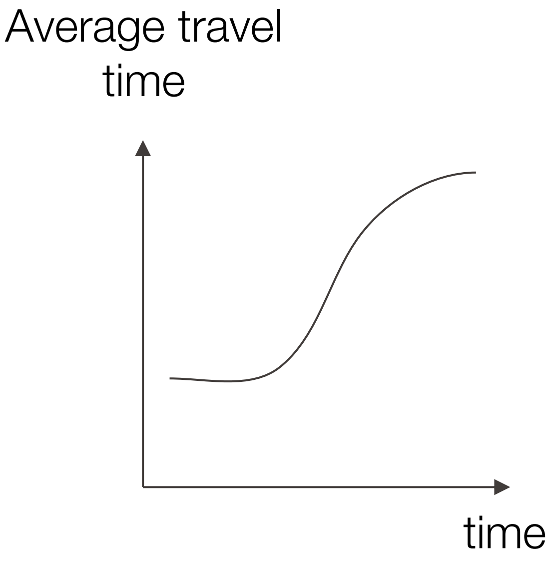
Triborough bridge (Kennedy Bridge), New York

Which pattern was observed in the evolution of traffic jams following the construction of the Triborough bridge?

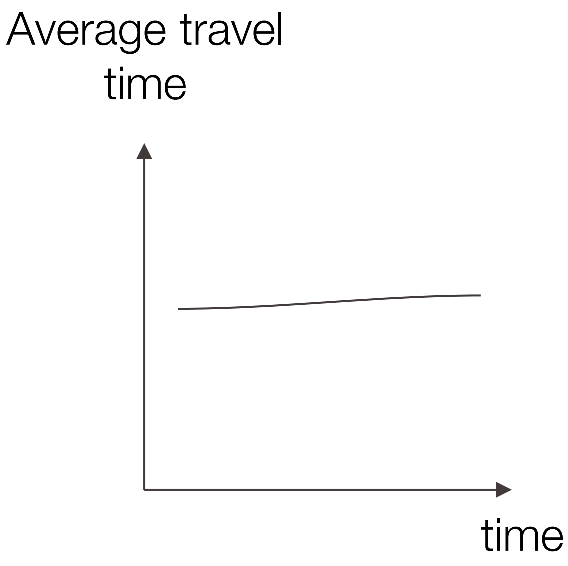
➔ We measure traffic jams through the average travel time



Option A

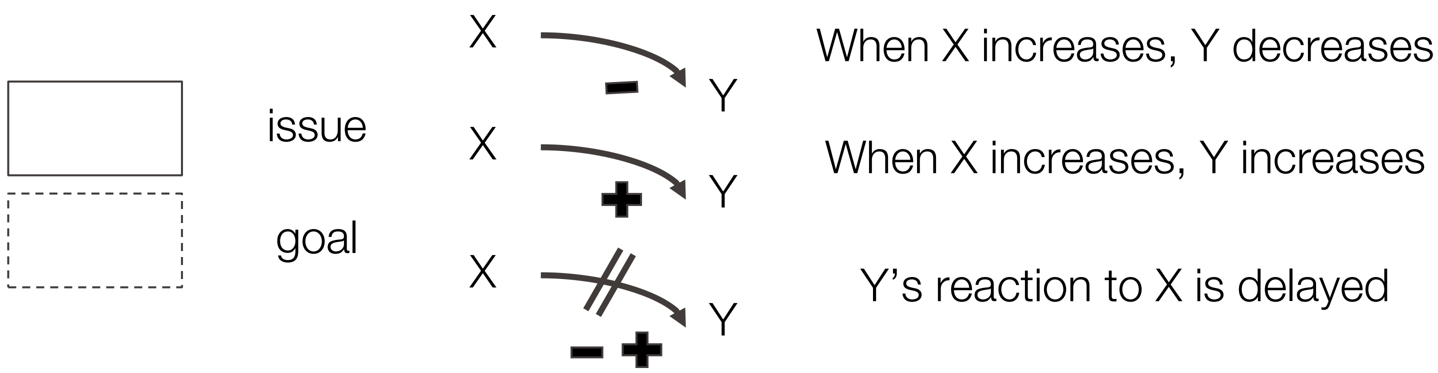


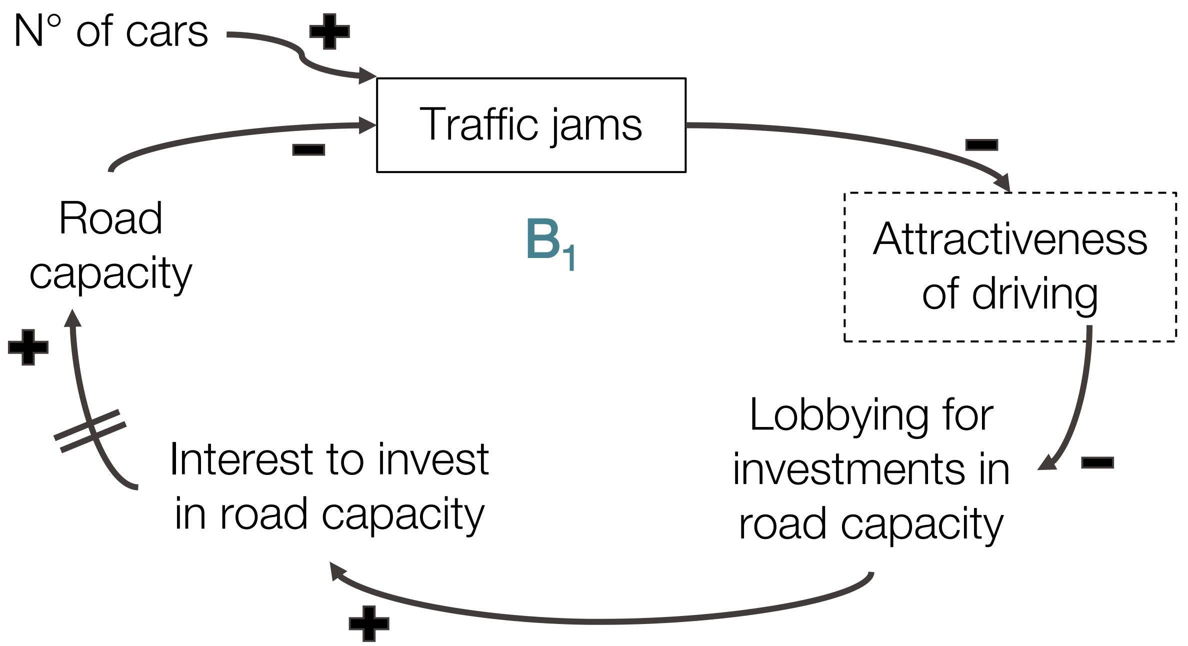
Option B



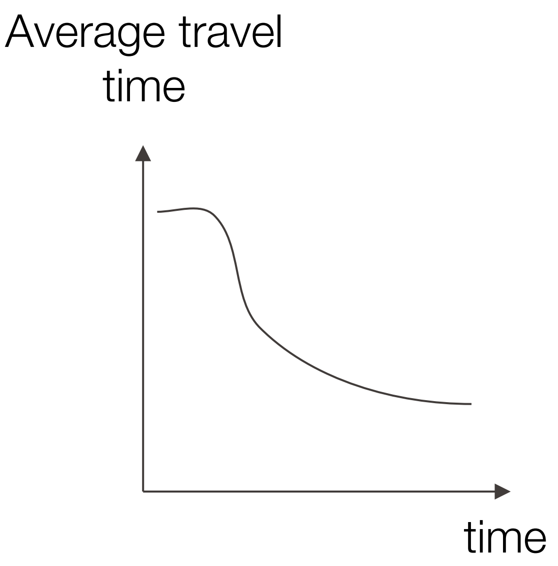
Option C

Meinherz 2021





EXPECTATION



Option A

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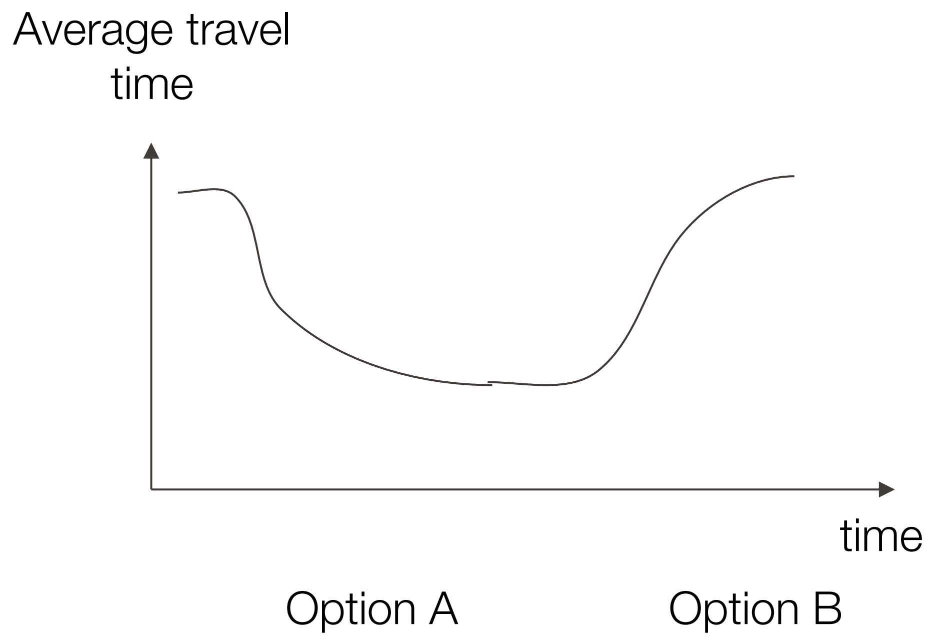
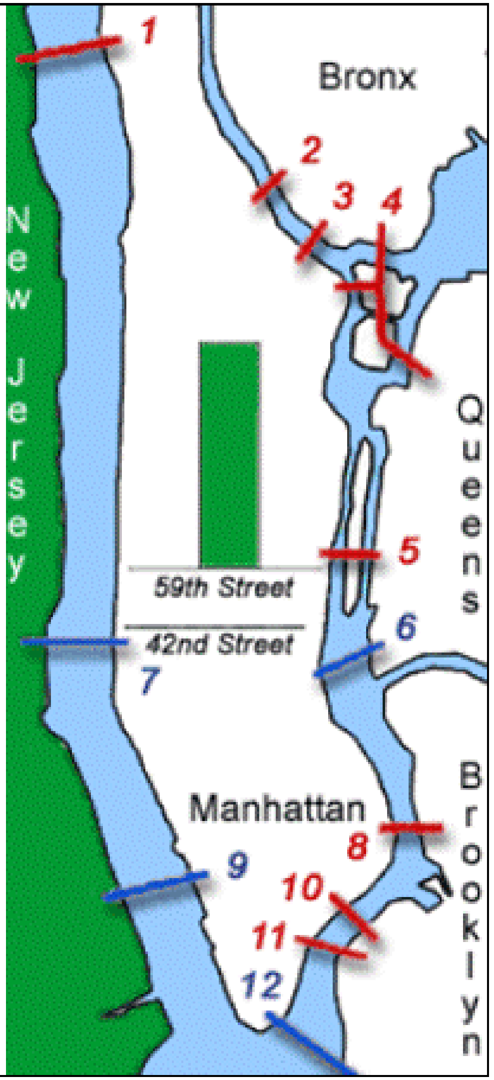
REALITY = rebound effect

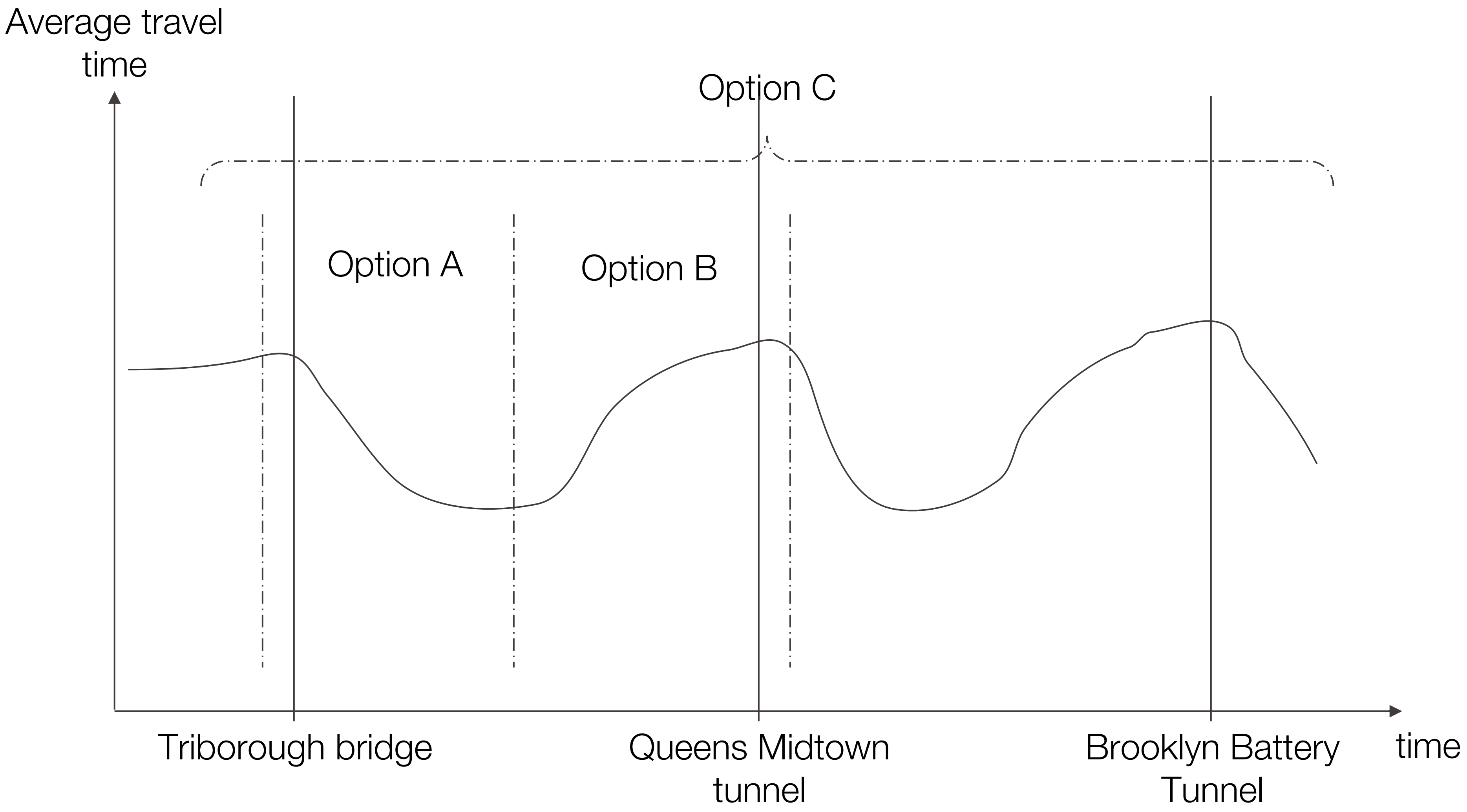


Meinherz 2021

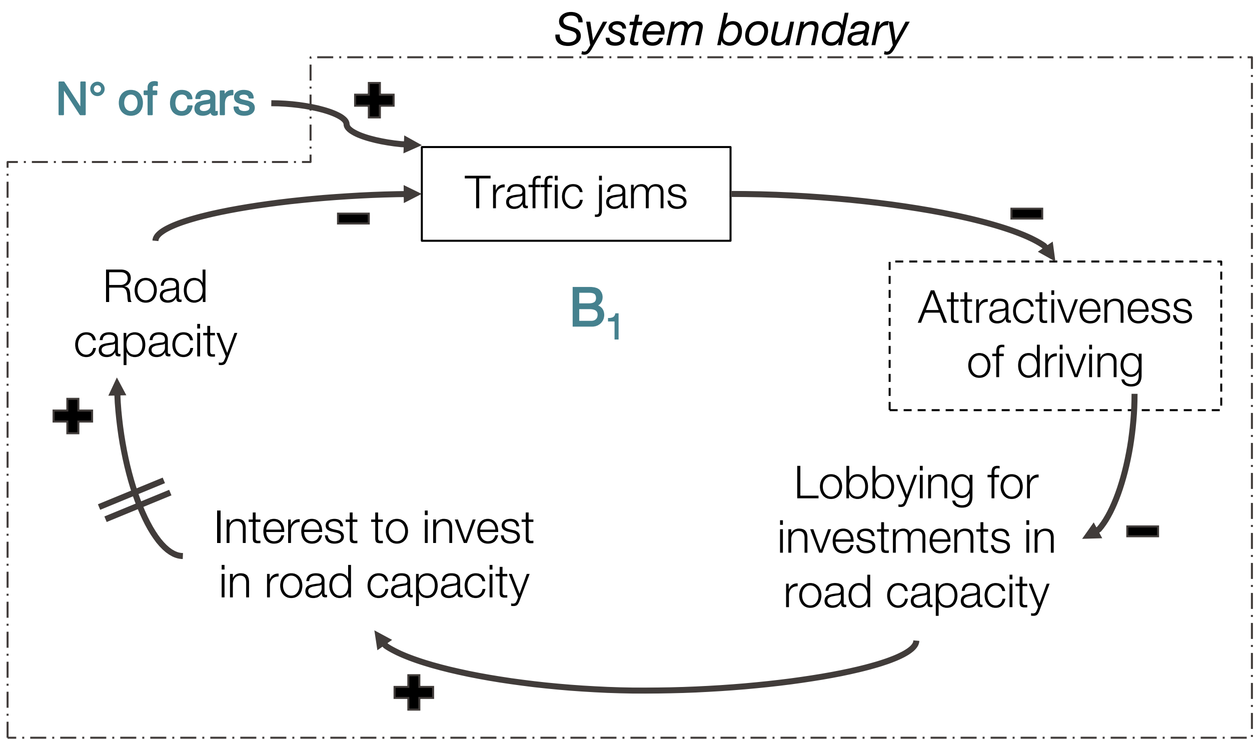
1. George Washington Bridge
2. Third Avenue Bridge
3. Willis Avenue Bridge
4. Triborough Bridge
5. Queensborough Bridge
6. Queens Midtown Tunnel
7. Lincoln Tunnel
8. Williamsburgh Bridge
9. Holland Tunnel
10. Manhattan Bridge
11. Brooklyn Bridge
12. Brooklyn Battery Tunnel

… plus many more in the agglomeration





Meinherz 2021



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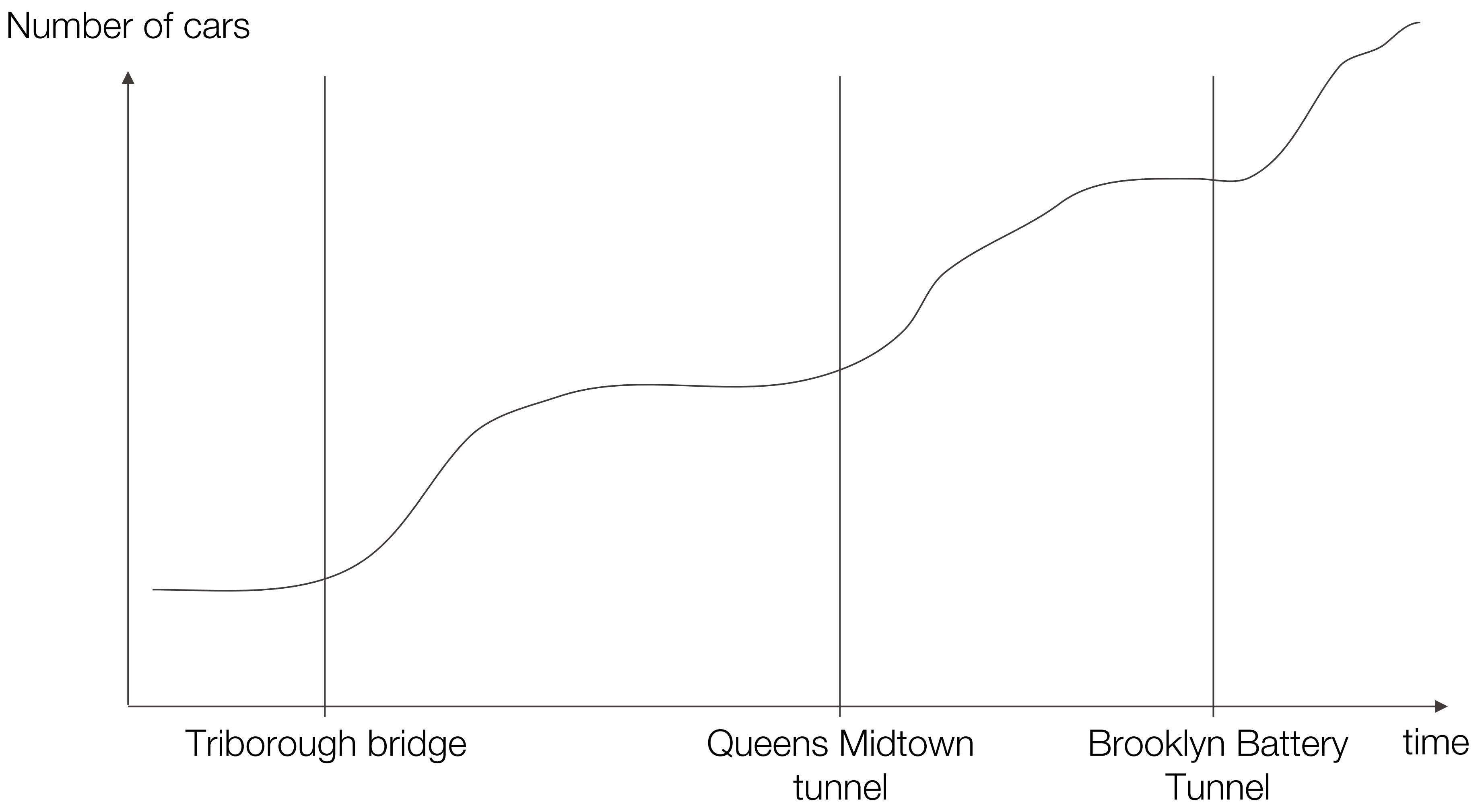
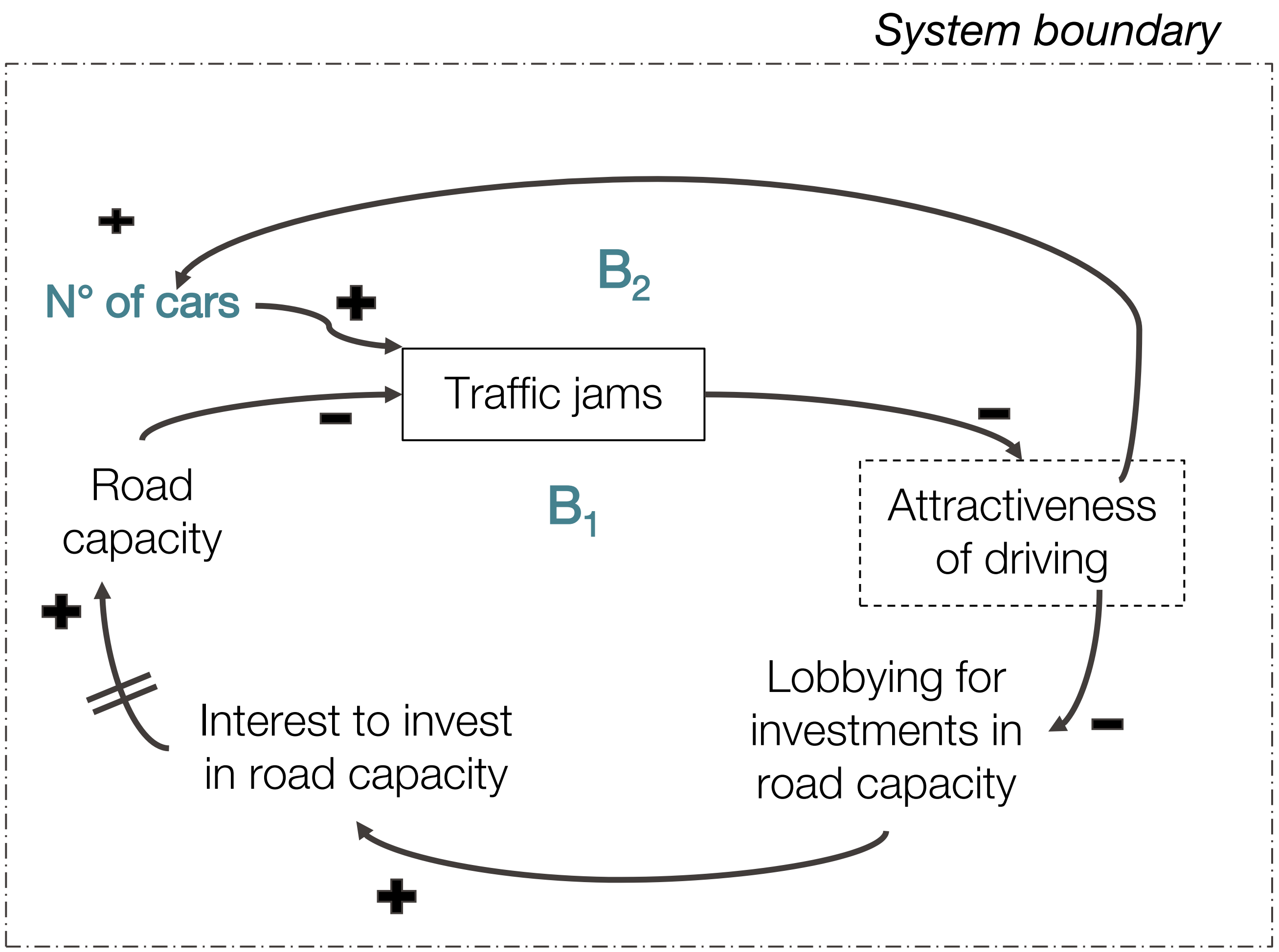


Meinherz 2021



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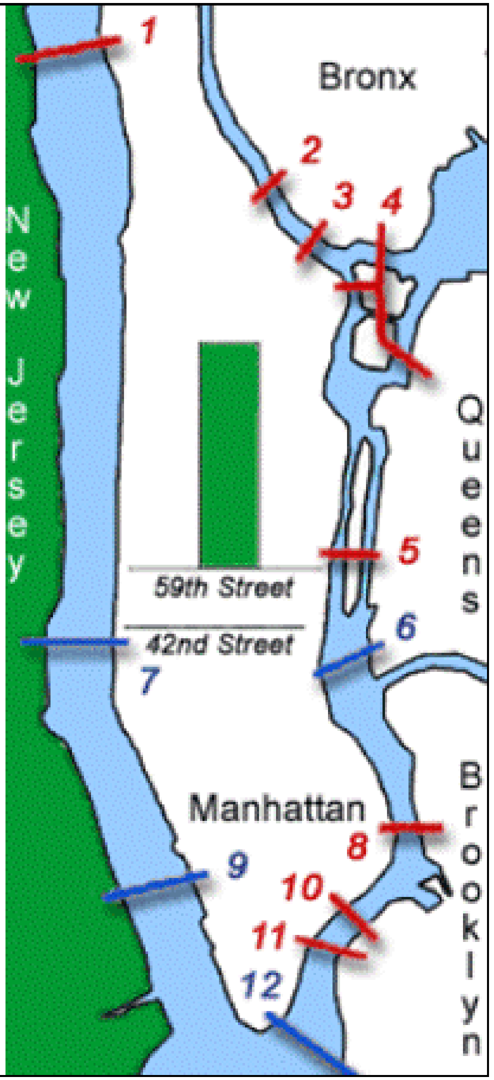
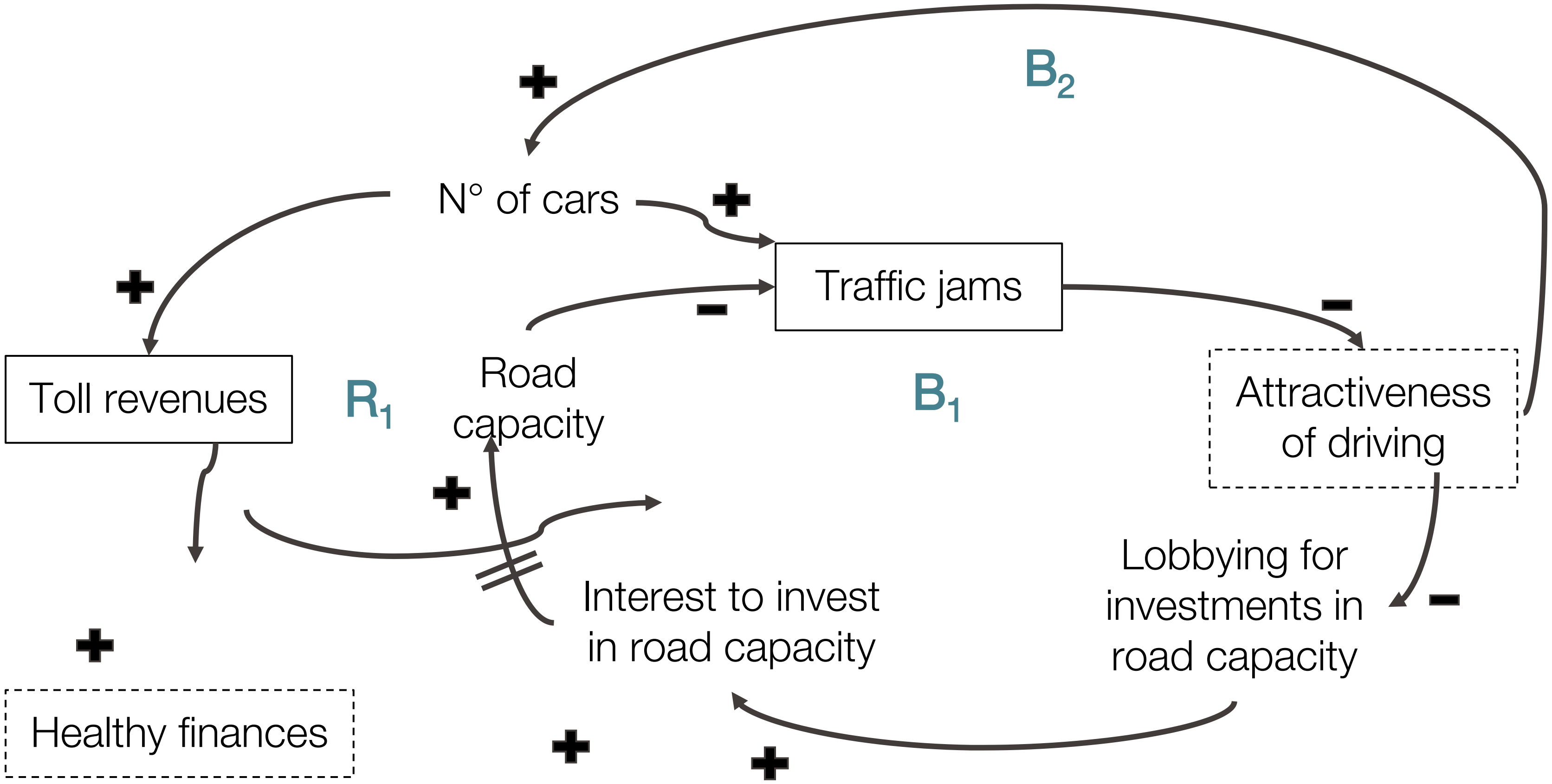


Robert Moses (1888-1981)

Bridges and Tunnels



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The system of automobility

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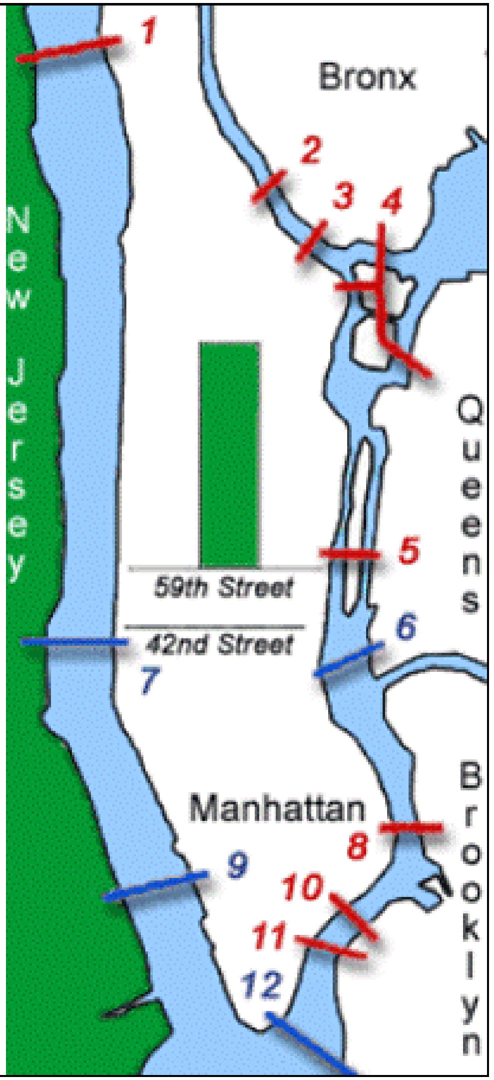
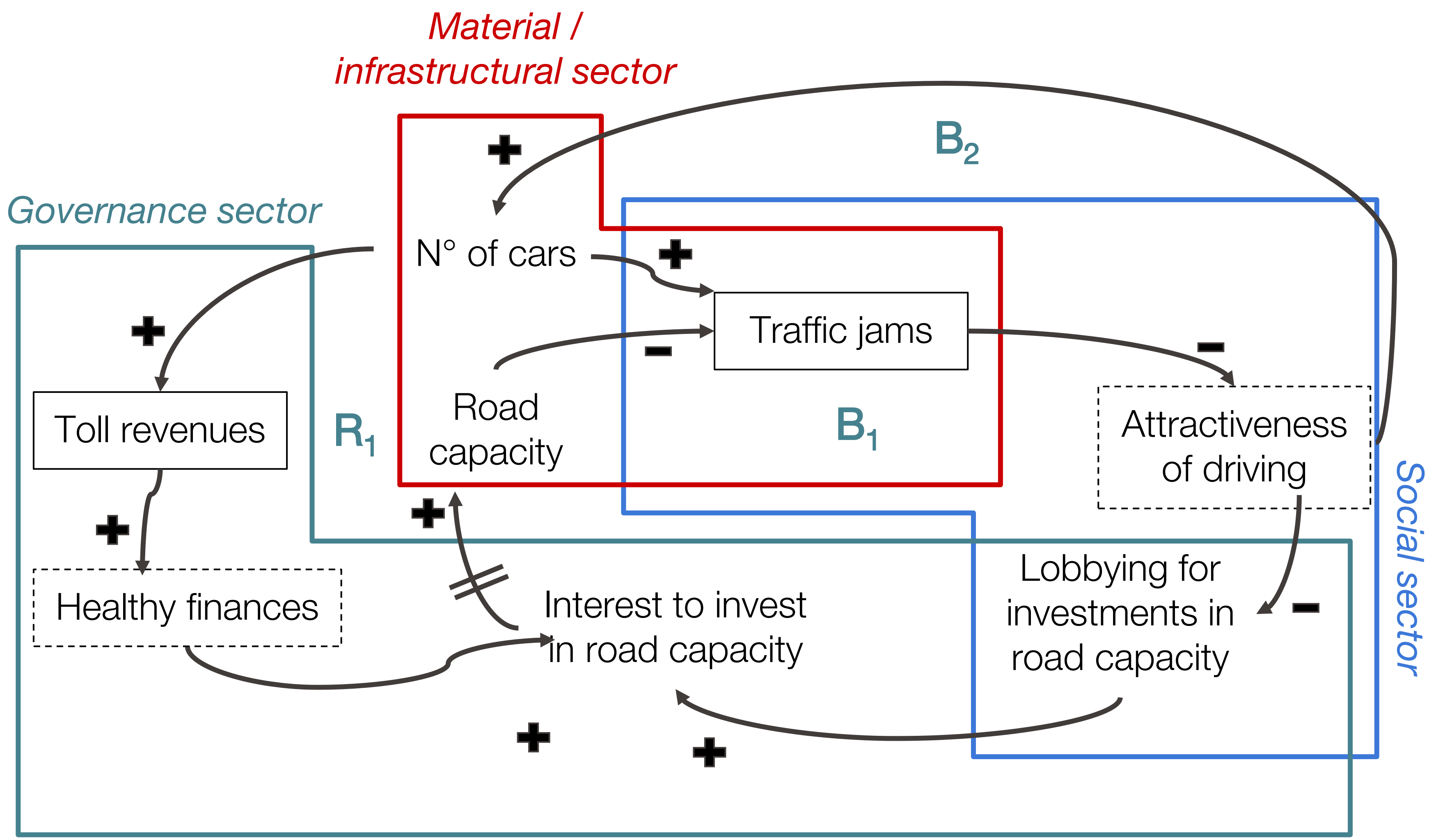


«The urban environment has 'unbundled' territorialities of home, work, business and leisure [...] [a]utomobility divides workplaces from homes, producing lengthy commutes into and across the city [...] undermining local retail outlets to which one might have walked or cycled, eroding town-centres, non-car pathways and public spaces.»
John Urry (2004)

Robert Moses (1888-1981)

Bridges and Tunnels



Meinherz 2021

Guiding principles

1 PROBLEM

- What is the problem that we're interested in? (e.g. How to promote cycling in Lausanne?)
- What variables/factors define/characterise this problem?

➔ ***SYSTEM FUNCTION***
➔ ***SYSTEM ELEMENTS/VARIABLES***

2 GOAL

- What do we want the state to be?
- What are the things that can be improved?

➔ ***TARGET VALUE(S)***
➔ ***ASSSESMENT OF SYSTEM ELEMENTS***

3 SYSTEM STRUCTURE

- What / who has an influence on the system element(s)?
- What / who is influenced by the problem variable(s)?

➔ ***INTERCONNECTIONS***
➔ ***SYSTEM BOUNDARIES***

4 SYSTEM DYNAMICS

- Where are feedback loops in the system, and what is their nature?
- Where are delays in the system?

➔ ***SYSTEM BEHAVIOUR***

«Each modeling discipline depends on unique underlying and often unstated assumption; that is, each modeling method is itself based on a model of how modeling should be done.»

Donella Meadows (1980)