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Systems Engineering - SySe
Chapter 2 – Systems Thinking

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Content

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Systems Thinking

1. What is the difference between Systems Science and Systems Thinking?
2. Systemigrams
3. System hierarchy
4. Systems Thinking

Why do we need System Decomposition?

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- … There's probably 10,000+ physical parts within a Model …

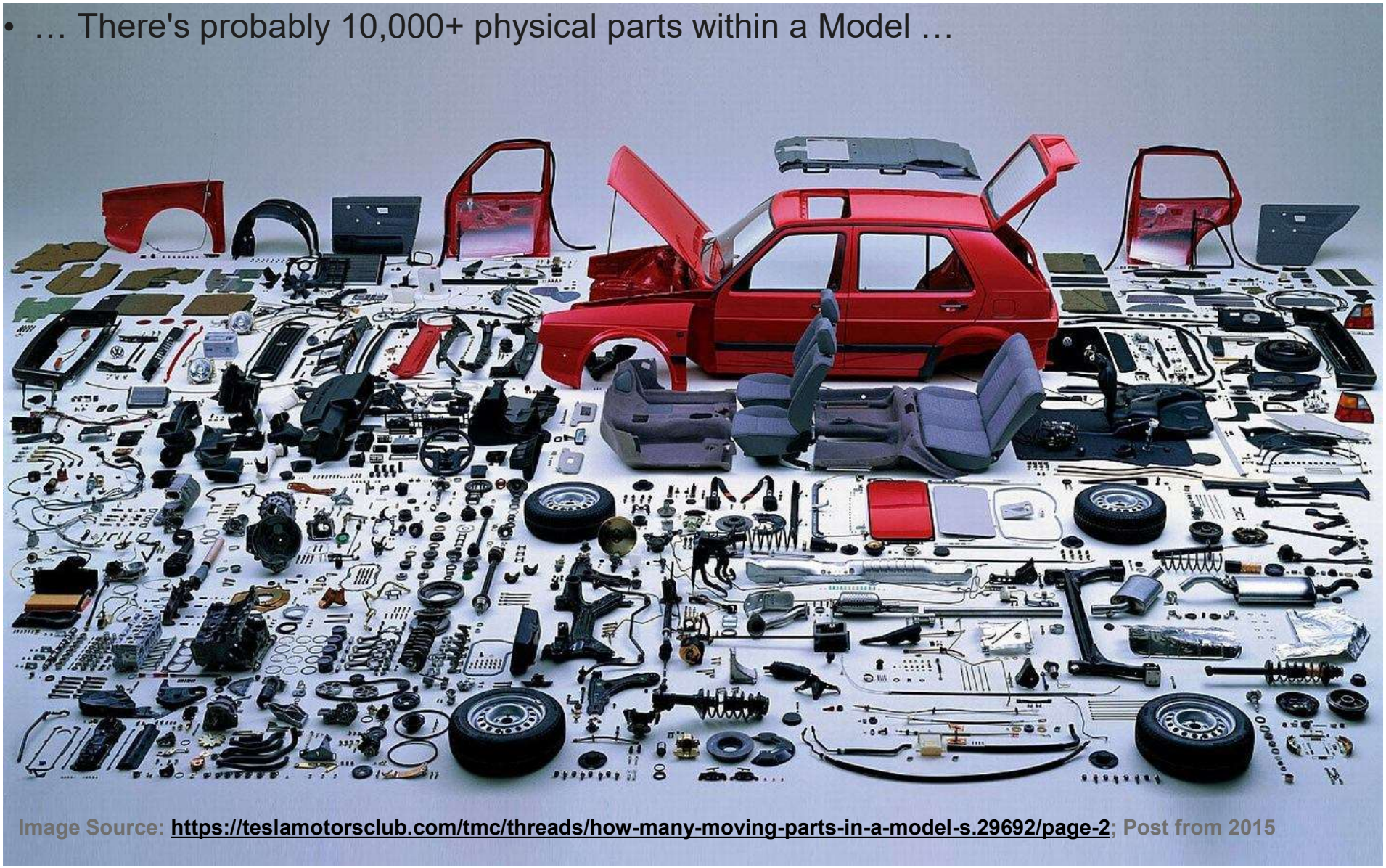

Image Source: https://teslamotorsclub.com/tmc/threads/how-many-moving-parts-in-a-model-s.29692/page-2; Post from 2015

Levels of decomposition

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- How many levels of decomposition (depth of drawing tree) do we need to describe the car shown in the previous picture?

  - 1
  - 2
  - 3
  - 4
  - 5
  - >6
  - I have no idea.

How many levels of decomposition?

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- **The magic number 7 +/- 2**

$$\#levels = \frac{\log(\#parts)}{\log(7)}$$

		~ #parts	#levels	
Screwdriver	(B&D)	3	1	simple
Roller Blades	(Bauer)	30	2	
Inkjet Printer	(HP)	300	3	
Copy Machine	(Xerox)	2,000	4	
Automobile	(GM)	10,000	5	
Airliner	(Boeing)	100,000	6	complex

(1) Assume 7-tree [Miller 1056]: https://www.musanim.com/miller1956/
(2) Table from: https://ocw.mit.edu/courses/16-842-fundamentals-of-systems-engineering-fall-2015/pages/lecture-notes/ Listing a primary source: Ulrich, K.T., Eppinger S.D., Product Design and Development Second Edition; MCGraw Hill, 2nd editiona, 2000, Exhibit 1-3

Systems Science and Thinking

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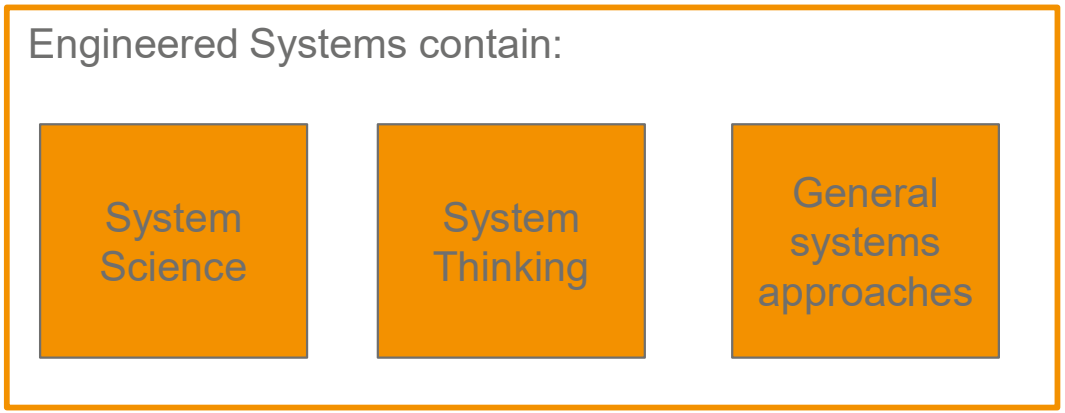
- **System science** adds research to systems engineering to understand complexity.
- **Systems science** considers interdisciplinary fields (i.e., nature, society) to form a solid theoretical basis with a common language and intellectual foundation for SE.
- Model-oriented systems engineering – highlights complex SE views of a system



- **Systems Thinking** provides mechanisms to perform deep analysis in multidisciplinary contexts.
- Examples of such methods are (1):
  - System dynamics – DYNAMO simulation language, STELLA, iTHINK

    e.g. clustering of system dependencies to increase efficiency
    almost physics-based/ rule-based in its approach
  - Soft System approach and action Research – develop alternative models additionally to original problem, Systemigrams

    not rule-based, system understanding comes through dynamic change of the graph, thinking through the system
  - Discovering patterns – to understand specific problems (SW design patterns, system architecture patterns, antipattern (why do we keep seeing the same problems occur over time), etc.)

https://www.sebokwiki.org/wiki/Systems_Thinking

Example – Stella Architect Modeling & Simulation

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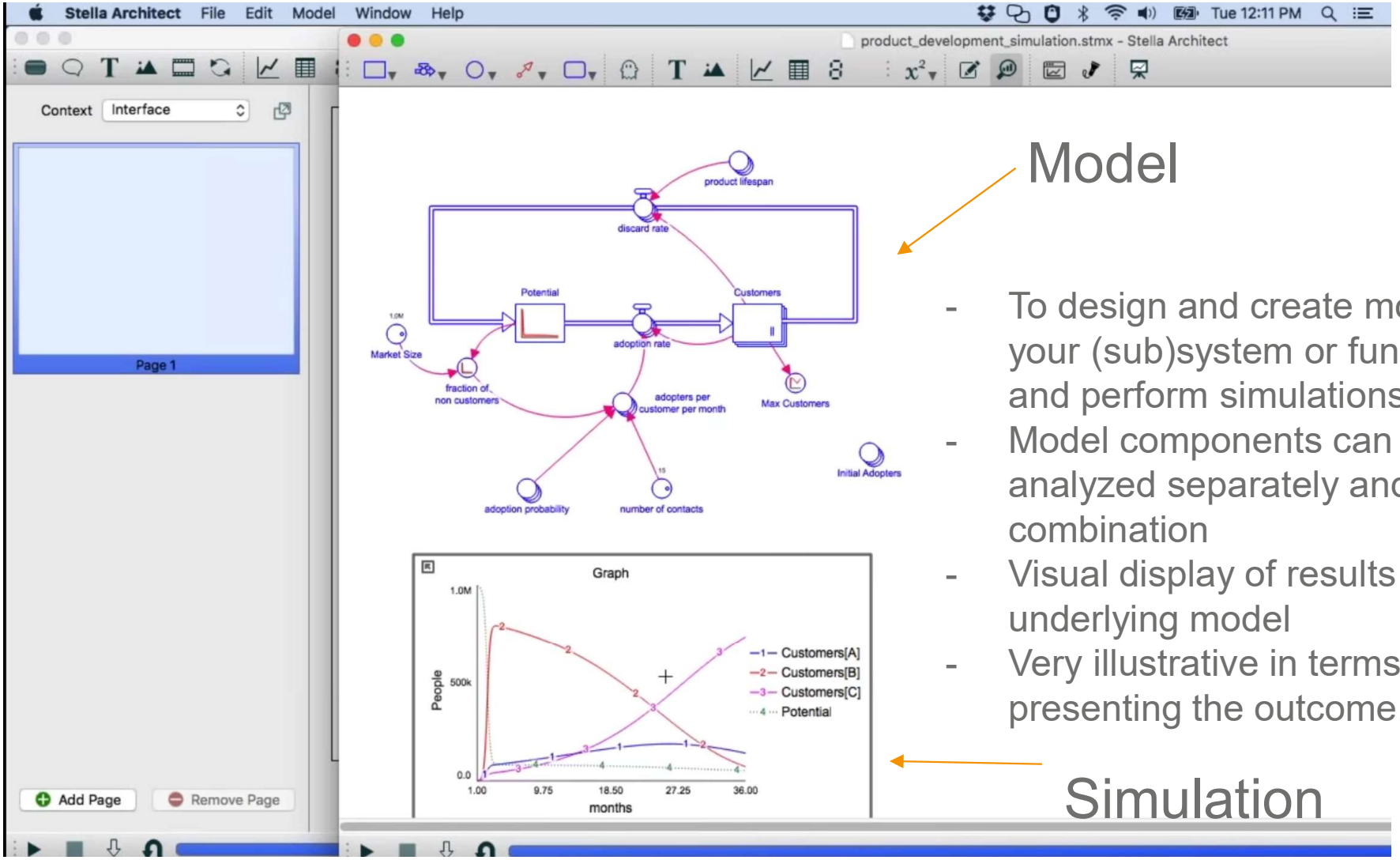

Model

- To design and create models of your (sub)system or functionality and perform simulations on it.
- Model components can be analyzed separately and in combination
- Visual display of results of the underlying model
- Very illustrative in terms of presenting the outcome.

Simulation

https://www.iseesystems.com/resources/webinars/

simulation to organise and predict system flow to a certain degree

Systemigrams

rather non-technical, focuses on connectivity and bigger picture

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… as a visual representation of the overall system

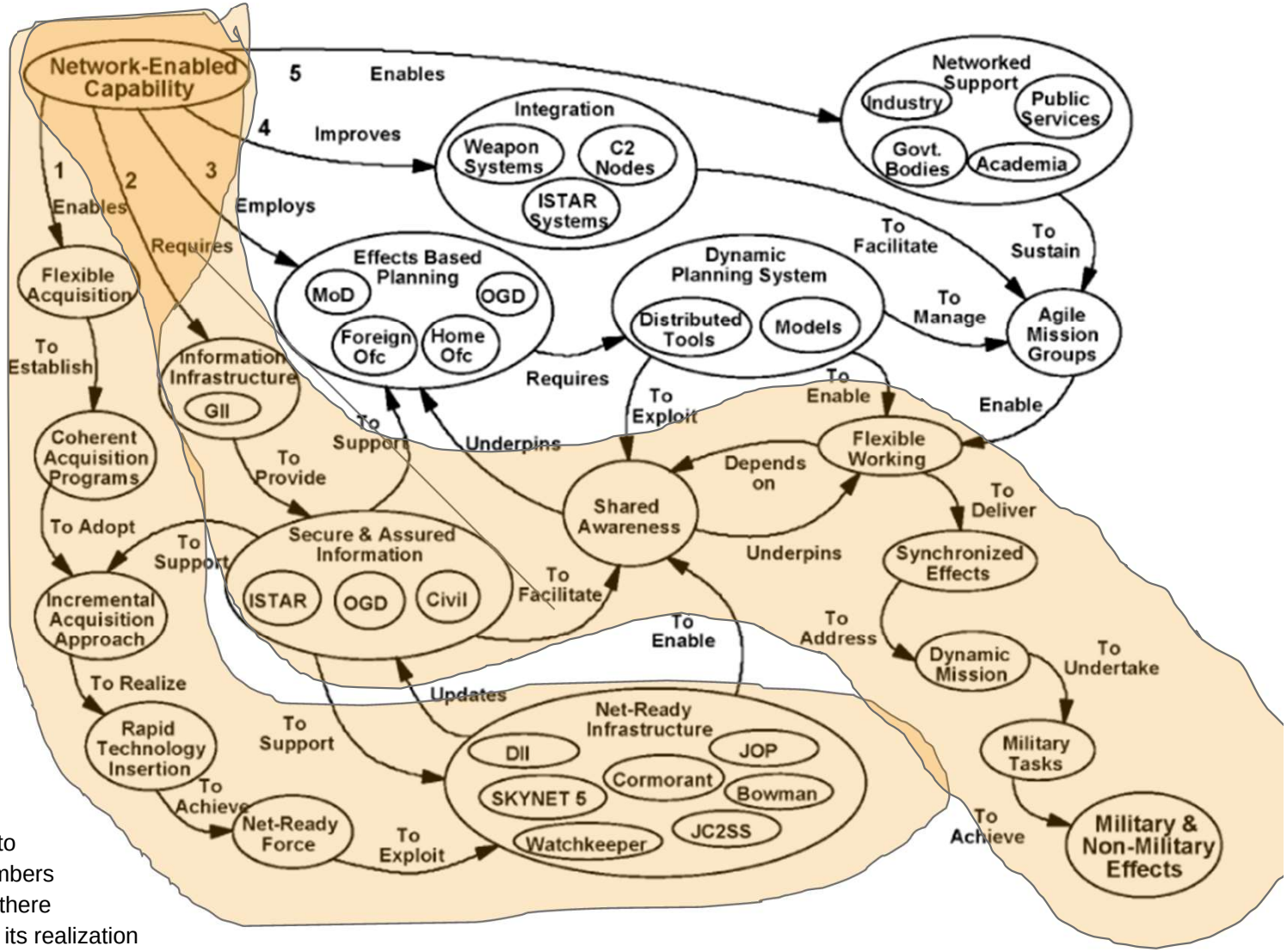
… highlight different perspectives of the system

… plot the interaction of variables in the system

… shows the relationship between entities and their impact on each other

… The verb on the arrow describes the effect.

… Tool to draw systemigrams online:
https://systemitool.sercuarc.org/



narrative approach: read graph from one node to the next, starting paths are designated with numbers
-> clarifies path to certain node and how to get there
as well as possible dependencies that play into its realization

Blair et al., Communicating Strategic Intent with Systemigrams: Application to the Network-Enabled Challenge, Systems Engineering, Vol. 10, No. 4, 2007 (https://incose.onlinelibrary.wiley.com/doi/abs/10.1002/sys.20079)

What does a Systemigram contain?

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1. **Nodes (Entities or Components) as** BOXES
2. **Links (Relationships or Interactions) as** ARROWS
3. **Narrative Flow:** from left to right or top to bottom
4. **Inputs and Outputs:** e.g., resources, data → at the edges of the diagram
5. **Feedback Loops as** CIRCULAR ARROWS
6. **Groupings** → breaking down complexity
7. **Boundaries as** DASHED LINES
8. **Legend and Labels:** legend, labels of relations, colour coding

What is system thinking?

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A question to all:

What is system thinking?

- toolsets to analyse, understand and represent a system visually
- possibility to find problems and (unwanted) dependencies
- method to understand the system on an abstract level
- understanding the system to optimize it

Discuss with your neighbour (~ 3 mins)

- Let's characterize the term system thinking by listening to the online course © by Systems Innovation : https://www.youtube.com/watch?v=Miy9uQcwo3U
- What are the key takeaway?

Analysis:
- gain understanding of system through breaking up a system into its parts
Reductionism: reduce system into its constiuents parts, descriptions of the system through the desc of its parts
- analysis of individual parts in isolation, then recombine and describe system through its parts
- depromotes the relations between the parts, system is just the sum of its parts
- good for systems with low interconnectivity and interdependency

Synthesis (Holism):
- gain understanding of systems through context of its relations and functioning
Holism: the whole can only be understood through the relations of its parts, parts cannot exist independently can only be understood through their interconnectivity and relation to the whole
- singular entity is analysed through its context and relations

Summary from video:
Analysis vs. Synthesis

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Analysis

- Understand a system by breaking a complex system into its smallest most basic parts to gain better understanding
- Analyse individual components in isolation.
- Recombine components into the whole system.
- Challenge: Low interconnectivity and interdependency between components.

Synthesis

- Understand system through the context of relations within a whole.
- Focus on relationships between the elements and how to combine them to form a connected whole.
- Viewing the system in context.

What does systems thinking involve?

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Knowledge of system engineering terms

(i.e., system, element, relation, attributes, SoS, system boundary, …)

Knowledge / experience about system thinking approaches

(i.e., understanding interactions, identifying cause-and-effect relationships in systems, identify patterns; identify trends; adopt different perspectives and viewpoints in a system; understand system structure and dynamics)

Knowledge of various representation options

(i.e.,

graphs, models, matrices, processes, data, …)

Representation granularity

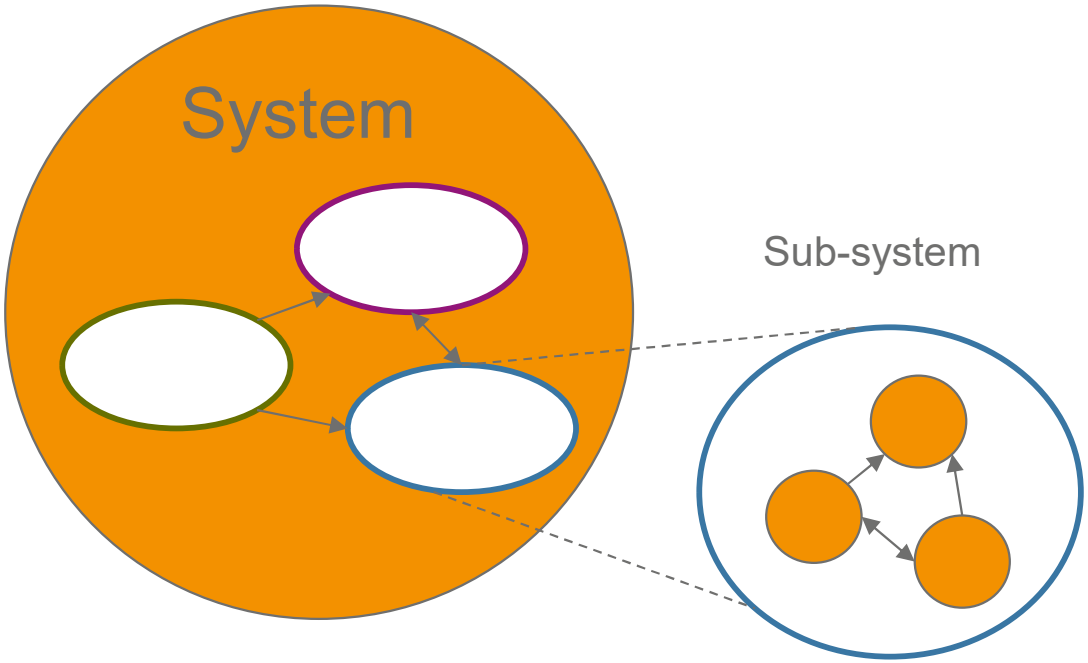
(i.e., which content should be presented with which detail?)

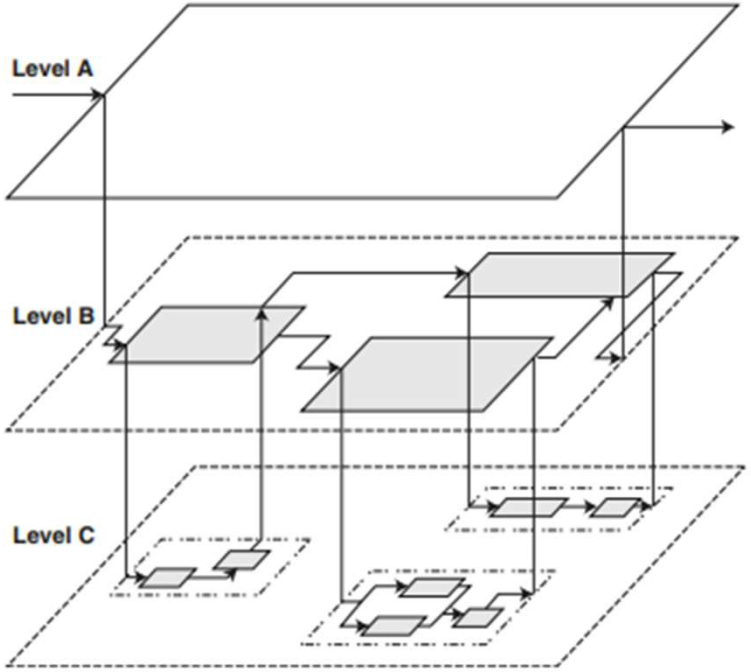
Representation perspective / viewpoint

(i.e., Who do I want to talk to? What should be shown with my representation?)

System Hierarchy

- Problem: Unmanageable number of elements and relationships
- Idea: divide the system into several levels and represent the system with subsystems.
  - First, a coarse structuring of the system --- Deliberately limited number of elements/ subsystems within the level
  - Each level deeper illuminates more detail or is broken down more finely.
  - Systems are presented as a black box system for the time being. The more detail is added, it goes from black to grey to white box representations.



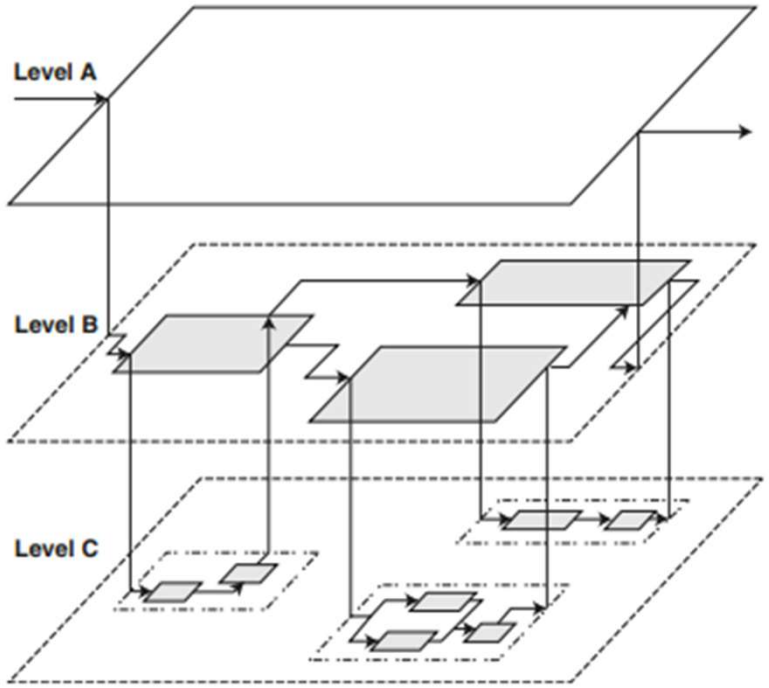


(1) Haberfellner et al., Systems Engineering Grundlagen und Anwendung, orell füssli 2018 (14. Auflage)

System Hierarchy

- Subsystem Consideration (Untersystembetrachtung):
  - What elements does a system consist of?

- Observation of the supersystem (Übersystembetrachtung):
  - To which superordinate system does an element/system belong?



(1) Haberfellner et al., Systems Engineering Grundlagen und Anwendung, orell füssli 2018 (14. Auflage)

System Hierarchy

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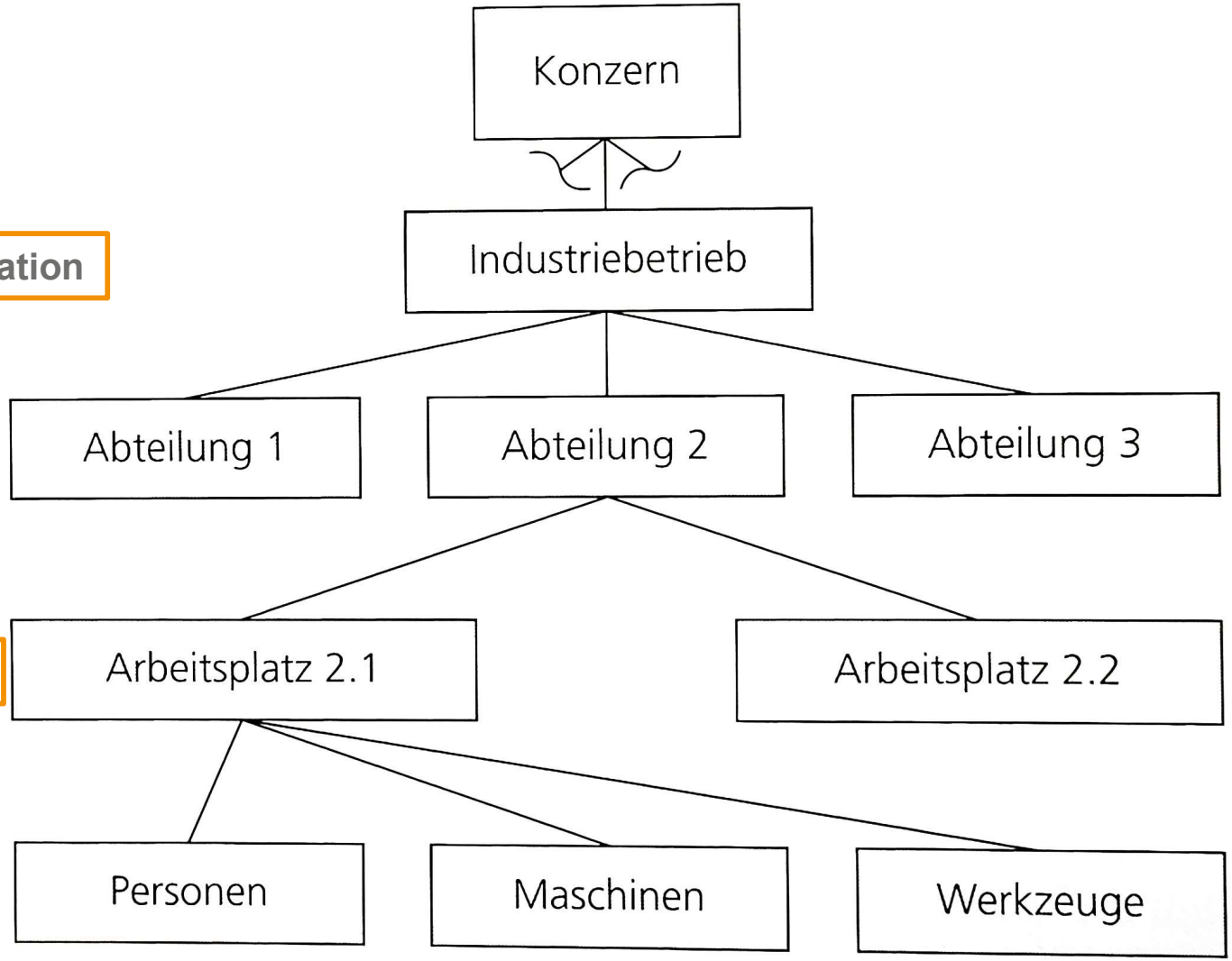
Supersystem

System under consideration

1st order subsystems

2nd order subsystems

Element level



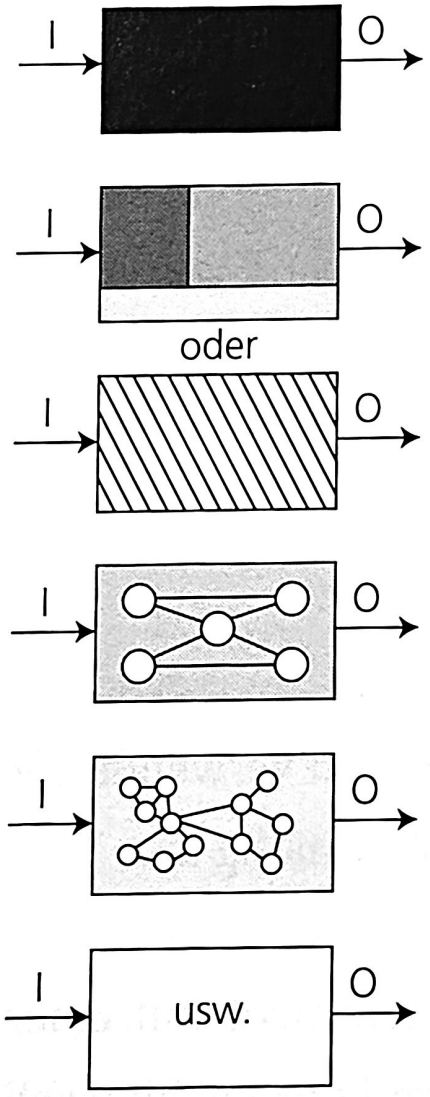
(1) Haberfellner et al., Systems Engineering Grundlagen und Anwendung, orell füssli 2018 (14. Auflage)

Whitebox? Grey box? Blackbox?

- Blackbox: Inner structure remains unknown or is not important. Main focus on input and output as well as the overall function

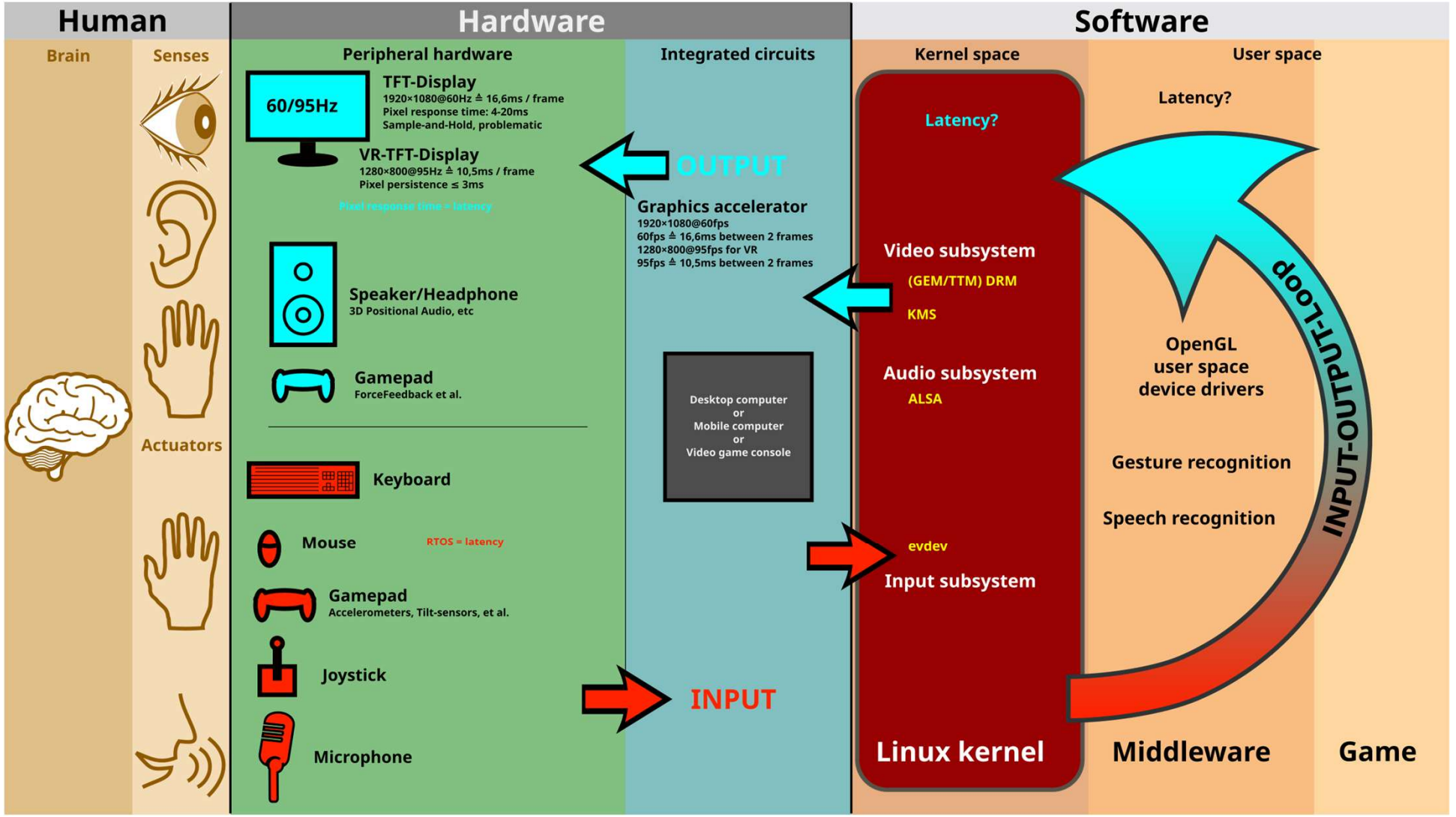
- Grey box: coarsely represented or partly structured or a hybrid approach.

- Whitebox: exact relationship between input and output is of great importance. For example, the inner connections should be considered analytically, etc.



(1) Haberfellner et al., Systems Engineering Grundlagen und Anwendung, orell füssli 2018 (14. Auflage)

Example



Source: https://de.wikipedia.org/wiki/Black_Box_(Systemtheorie)#/media/Datei:Linux_kernel_INPUT_OUPUT_evdev_gem_USB_framebuffer.svg

System Thinking

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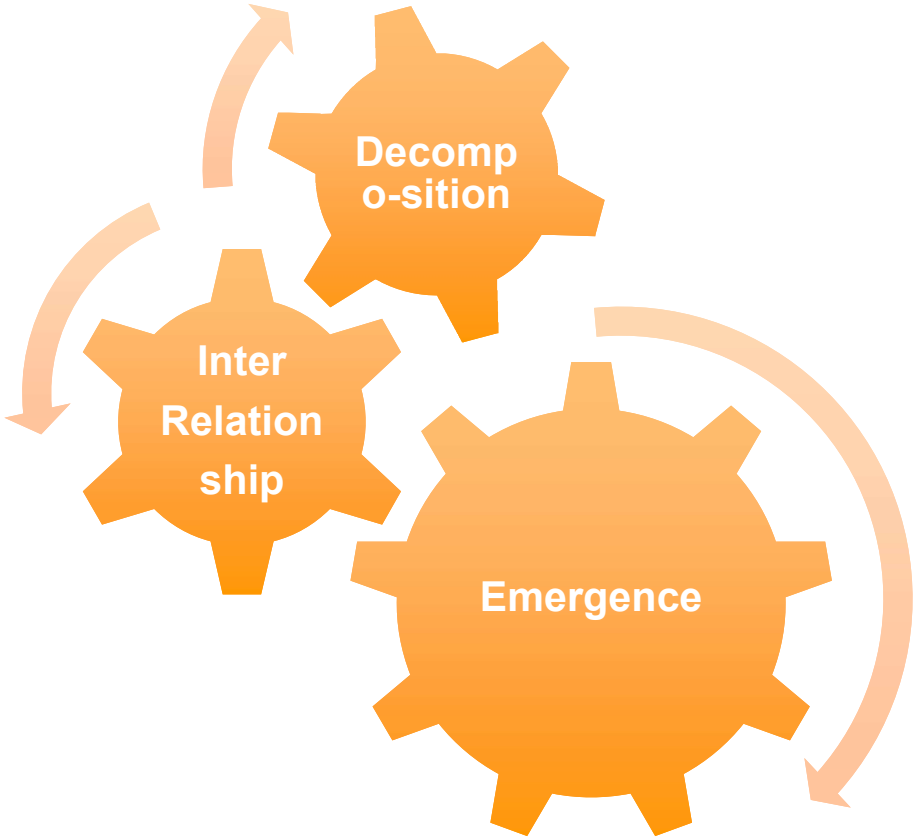
- … is not thinking systematically! It is, too, but it goes further.
- System Thinking provides mechanisms to analyze a system.
- A (complex) system is built of individual parts and sub-systems that are combined to create an overall system.
- System Thinking looks at those pieces and identifies the interaction and relationship of those pieces.
- This involves:
  - system decomposition – so each individual piece is evaluated
  - Look at relationship of the individual pieces
  - Evaluate emergent behavior when combining the pieces, intended and unintended.



System Thinking Tasks

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1. Identify the system
2. Decompose the system
3. Identify relationships
4. Determine emergence

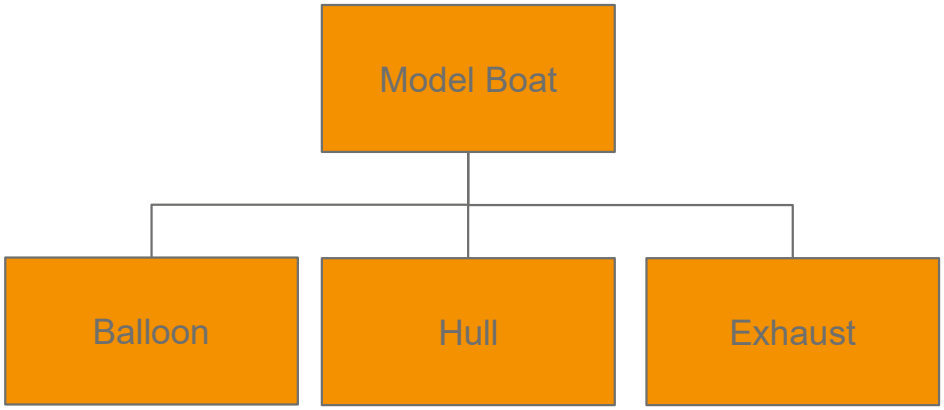
1. Identify the system

- The system is identified by naming its **form** and **function**.
- The form of a system is the description what a system is.
- The function of a system describes what a system does.
- Examples:
  - TH Rosenheim:
    - Form: University of Applied Sciences
    - Function: offers courses of studies to obtain a Bachelor or Master degree
  - Airport
    - Form: Airport
    - Function: organizes airplane arrivals and departures
- The form is about the **structure** of the system: how are objects of the form connected → arrangement, layout
- The combination of different objects result in different **emerging behavior** (see step 3 on finding relations).

Primary system form: Research Boat
Primary system function: demonstrate boat propulsion
Description: Research boat as overall system, the purpose is to demonstrate how boats are moving forward when provided with energy.

2. Decompose the system

- Analyze your system by **taking it into it‘s components.**
- The level of detail will grow, so think of relevant pieces first, which then can be taken down into individual components, and so on.
- Identify the form and function of each sub-component.
- Identify the boundaries between the components: what belongs to the component, what is outside the component?



Remember from lecture 1: System Hierarchy

Nr. 1: Motor; Form: Balloon; Function: contains air
Nr. 2: Boat hull; Form: wooden boat body; Function: swims in water
Nr. 3: Exhaust; Form: wooden tube; Function: blow air into water.

3.&4. Identify relationships and determine emergence

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- **Emergence**: the system consists of individual pieces; each piece has its own function. Once they are combined and put into relation, they form a function that is greater than the function of the individual pieces.
- Types of emergence: functional, performance, reliability, maintainability, safety.

- The system pieces can be related based on forms, i.e., the main wing is attached to the fuselage of the airplane. The passenger seats are arranged inside the fuselage, etc. → static

- The system pieces can be related based on its function, i.e., when combining the lifting properties of the main wing and other components (engine, winglets, tail, etc.) the airplane flies and can transport people from A to B. → dynamic

- **Predict emergence**: how must component functions be related to achieve a certain functionality of the overall system?
  - Analyze experimentally
  - Analyze by models and simulation
  - Analyze on past experience

Identify Form and Function

Identify Form and Function

Form: container
Function: contains material

Form: sand
Function: diverse, i.e., house construction, glass production, …

What could be emergent behaviour?

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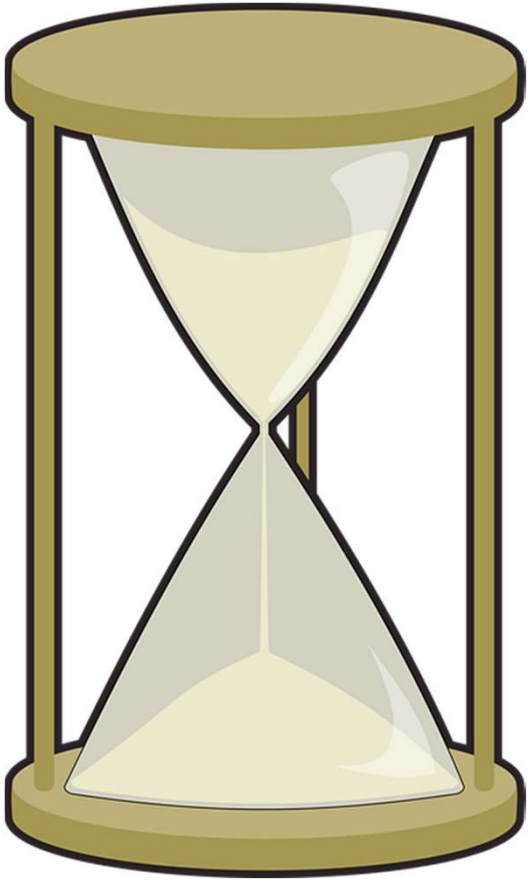

Emergence and Boundary

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Intended emergence: boat swims forward when releasing the finger from the exhaust tube
Unintended emergence: boat is not on water, air releases through tube, but boat does not go forward.


Baker Ross
Craft-it!
2
Wooden Trebuchet Catapult Kits
WARNING:
CHOKING HAZARD –


Craft-it!
8 pcs
Wooden Gliders


Baker Ross
Craft-it!
2
Wooden Car Kits


Ross
Craft-it!
2
Wooden Sailboat Kits

Summary

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- Systems Engineering is a highly interdisciplinary approach summarizing a set of tools that support the process towards a successful realization

- Systemigrams
  - … as a visual representation of the overall system
  - … highlight different perspectives of the system

- Systems Thinking: mechanisms to analyze a system by separating the system into form and function, by identifying the relationships as well as emerging behavior.

- Systems Thinking can be performed in four steps:

  - Identify the System
  - Decompose the system
  - Identify relationships
  - Determine Emergence and Boundary

Time for questions …

Image from: https://pixabay.com