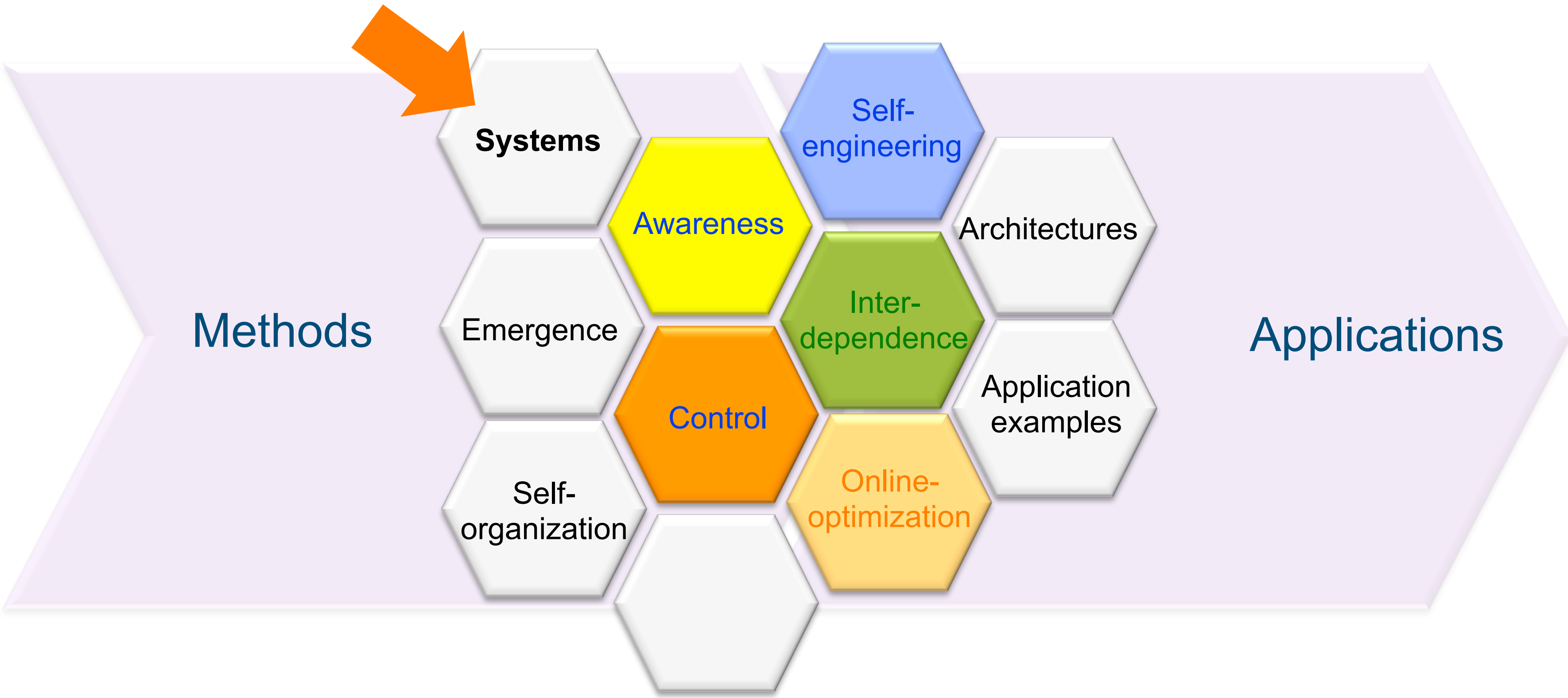
Methods
Systems
Awareness
Self-engineering
Architectures
Emergence
Inter-dependence
Application examples
Control
Self-organization
Online-optimization
Applications

Preconditions

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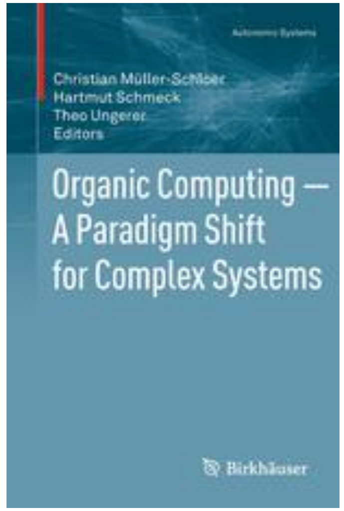
Objectives

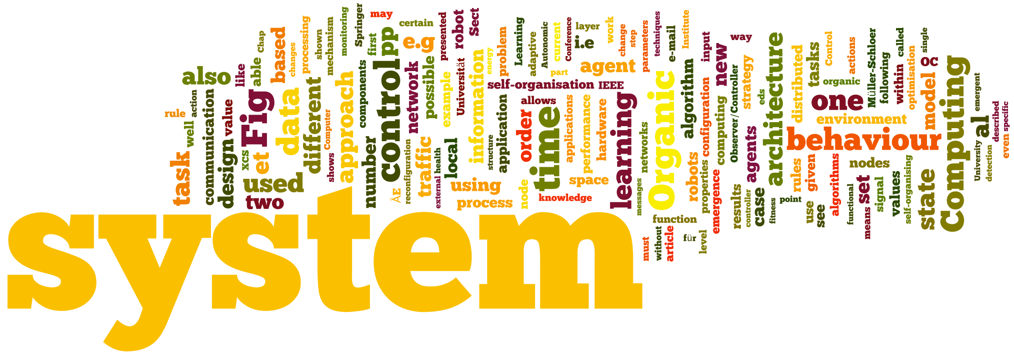
Terminology, definition of term „system“, chracteristics of systems

Content

- ❑ Systems thinking
- ❑ Definitions of „system“
    - Abstractions and aspects
    - Structure and behaviour
    - System boundary
    - Some more system types
- ❑ Hierarchy and holarchy
- ❑ Complexity

OC Compendium





- ❑ Systems thinking is popular.
- ❑ Key words
  - integrated / holistic / ganzheitlich
  - interdisciplinary
  - sustainable (nachhaltig)
  - cooperative (synergistic)

1. A characteristic aspect for thinking in systems is the realization that there is no unique single view of objects. Different points of view and opinions have to be combined to determine a complete evaluation of an object.
2. There are no isolated objects. Objects are always interacting with other objects (and the observer!) and are formed and affected by their environment → Interdependence

ISE SRA

Old	New
Singular / single science	Interdisciplinary
Object-oriented	Process-oriented
Mechanistic	Organic, cybernetic
Separated objects (atomistic)	Related objects, combined into systems
Analytic	Integrated (synthetic)
Linear functional chains	Networked process loops, process thinking
Exact mono-causal-logic approach (implications of the whole system neglected)	Interdependent structure with fuzzy parameters, conditional
Hierarchy, unilateral power relationships	Network, holarchy, bi-lateral power
Descartes/Newton	Alfred N. Whitehead

- Alfred North Whitehead
  - 15.2.1861 – 30.12.1947
  - British mathematician and philosopher, collaborated with Bertrand Russell
  - Defined “Process Philosophy”, a comprehensive metaphysical system departing radically from western philosophy:
    - “Reality consists of events rather than matter.
    - Events cannot be defined apart from their relations to other events, thus rejecting the theory that reality is fundamentally constructed by bits of matter that exist independently of one another.”
    - We must see the world as a web of interrelated processes of which we are integral parts, so that all of our choices and actions have consequences for the world around us.”
  - Literature: C. Robert Mesle, Process-Relational Philosophy: An Introduction to Alfred North Whitehead (West Conshohocken: Templeton Foundation Press, 2009), 9.

- **Systems thinking** is any process of estimating or inferring how local policies, actions, or changes influence the state of the neighboring universe.
  - It also can be defined, as an approach to problem solving, as viewing "problems" as parts of an overall system, rather than reacting to present outcomes or events and potentially contributing to further development of the undesired issue or problem. *)

*) http://en.wikipedia.org/wiki/Systems_thinking

- Some observations:
  - A system is a community of single entities situated within an environment.
  - A system is a dynamic and complex whole, interacting as a structured functional unit.
  - Systems are often composed of entities seeking equilibrium but can exhibit oscillating, chaotic, or exponential behavior.
  - Interdependence: Each parameter of the system exists depending on other parameters – the result is a product of stimulating and/or repressing processes.

- Systems thinking means:
  - Interdependence of objects and their attributes - Independent elements can never constitute a system.
  - Holism: Emergent properties are not possible to detect by analysis, but they can only be defined by a holistic approach.
  - Open System: In a closed system inputs are determined once and constant; in an open system additional inputs are admitted permanently from the environment.
  - Process thinking: Transformation of inputs into outputs is achieved by a goal-oriented process.
  - Regulation: A method of feedback is necessary for the system to gain stability.
  - Hierarchy: Complex wholes are made up of smaller subsystems.
  - Differentiation: Specialized units perform specialized functions.
  - Convergence: There are alternative ways of attaining the same objectives.
  - Divergence: Alternative objectives can be reached from the same inputs.

- Structure: Each thing consists of parts, with each part consisting of parts again.
- Interdependence/interaction: In nature all things are interacting with other things.[1]
- Interdependence/interaction = Exchange of information[2]

[Zycha 97]

1) Nature - as we observe it - is the result of a long-lasting evolutionary process. By principle, it works holistically. Technology must be seen as a part of nature.

2) Cf. „fit“ (= Passung), in-formation, structural coupling (Maturana, Varela: „Autopoiese“; Vollmer: „Evolutionäre Erkenntnistheorie“)

- Impact of the complete interconnectedness of things:

1. Small changes at one position within the system effect major changes at other positions and for the whole system.
    - Cf. chaos, butterfly http://www.g-o.de/index.php?cmd=focus_detail2&f_id=141&rang=10)
2. Holistic thinking implies taking humans into account as part of the system. This leads to the fact that strict objectivity is not possible. At best: inter-subjectivity.
3. Thinking in terms of interdependencies (Wirkungszusammenhänge): What are the impacts of interacting with equilibrium systems?
    - See also: Gaia-hypothesis, Lovelock, Margulis

- Consequences of interconnectedness (engineering point of view):
  4. We need methods/techniques to artificially develop balanced systems.
  5. Structural thinking[1] or analysis (Cartesian / Newtonian / Aristotelian) have to be extended by consecutive re-composition (synthesis).

not replaced!!

[1]) Structural thinking is based on the **analysis** of complete systems (process from an abstract level toward a detailed level). This will remain a necessary part of systems thinking and will not become obsolete!

- Introduced by Lynn Margulis (microbiologist) and James Lovelock (chemist, biophysicist and medical scientist) in the 1960ies.
- James Lovelock defined Gaia as

  a complex entity involving the Earth's biosphere, atmosphere, oceans, and soil; the totality constituting a feedback or cybernetic system, which seeks an optimal physical and chemical environment for life on this planet.

- With his initial hypothesis, Lovelock claimed the existence of a global control system of surface temperature, atmosphere composition and ocean salinity. His arguments were:
  - The global surface temperature of Earth has remained *constant*, despite an increase in the energy provided by the Sun.
  - Atmospheric composition remains *constant*, even though it should be unstable.
  - Ocean salinity is *constant*.

See also: http://de.wikipedia.org/wiki/Gaia-Hypothese

- General statement
  - Earth‘s surface (including the whole biosphere) can be considered as one living organism.
  - The biosphere (the entirety of all organisms) creates and preserves the environment and its conditions – which allows for life and the evolution of other complex organisms.
  - Earth‘s surface is a dynamic system, which stabilizes the whole biosphere using feedback mechanisms and control loops.
  - Creatures are characterized by their ability to self-organize (and use Autopoiesis).
- Criticism: 4 complex parts, not one Gaia
  - Co-evolutionary Gaia: Life and the environment have co-evolved. This was already accepted scientifically and not new.
  - Homeostatic Gaia: Life maintained the stability of the natural environment, and this stability enabled the continued existence of life.
  - Optimizing Gaia: Gaia shaped the planet in a way that made it an optimal environment for life as a whole. This is not testable and therefore not scientific.

- A system is a set of elements (or parts), which are interacting with at least one other element. A system as a whole possesses characteristics, which are more than the sum of the characteristics of its parts. (Thomé)

see also: emergence!

- Comments:
  - Trivial definition?
  - What is **not** a system? An electron?

ISE SRA

- System = Composition (σύστημα, structure, put together, connected)
- „A system is everything, which is worth a name.“
- von Bertalanffy: „A system is a complex of entities interacting with each other.“

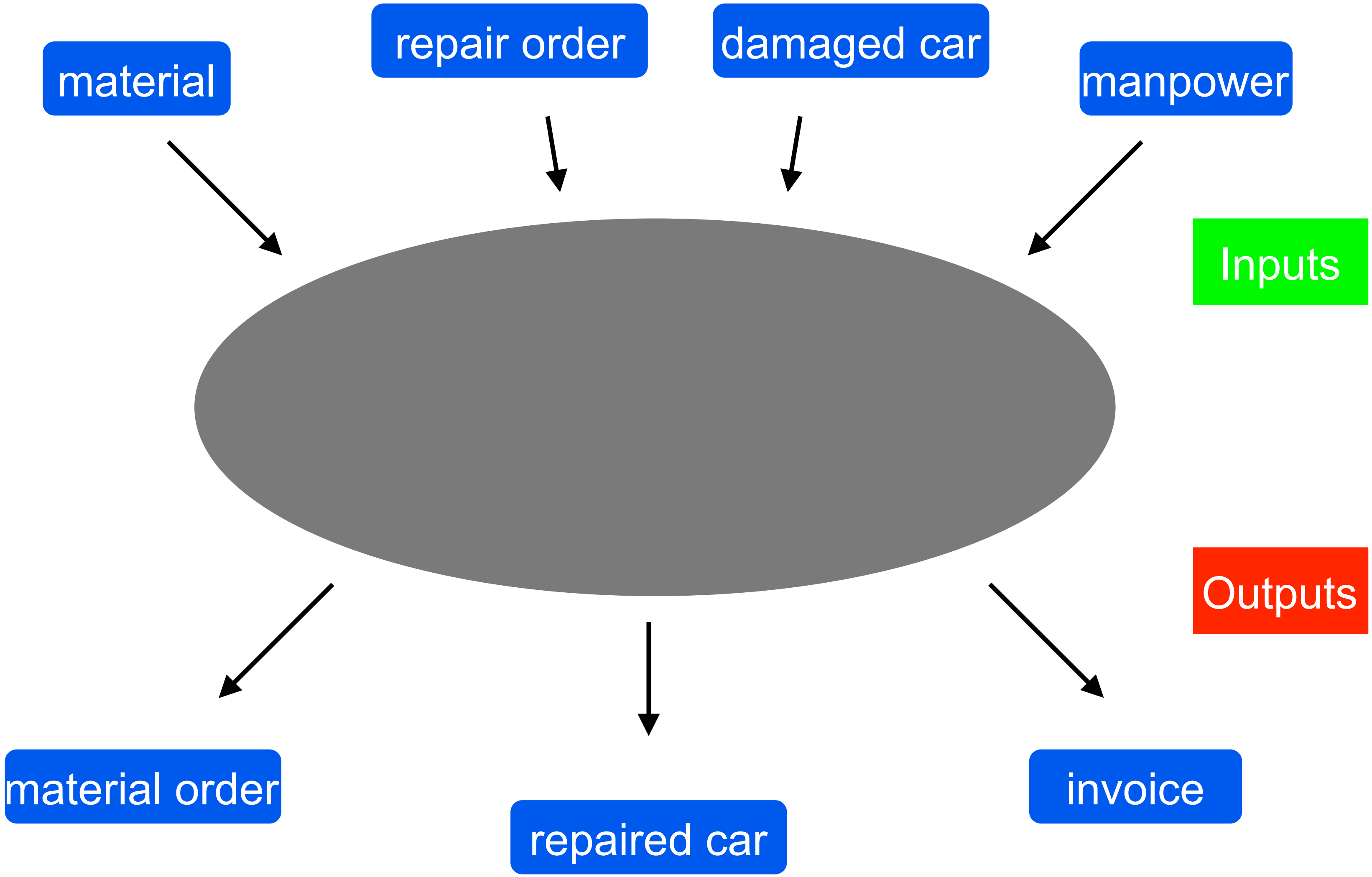
  => not really useful – too abstract!
- Further considerations:
  - The term „system“ implies an observer!
  - The observer forms systems to solve problems.[1]
    Each perceptible system is a model of reality – consequently an abstraction.
  - Forming a system (= modeling) implies a system objective (a meaning). [2]
  - --> Arbitrariness? Utility!
- System = useful model (abstraction)

“Wahr-nehmung”

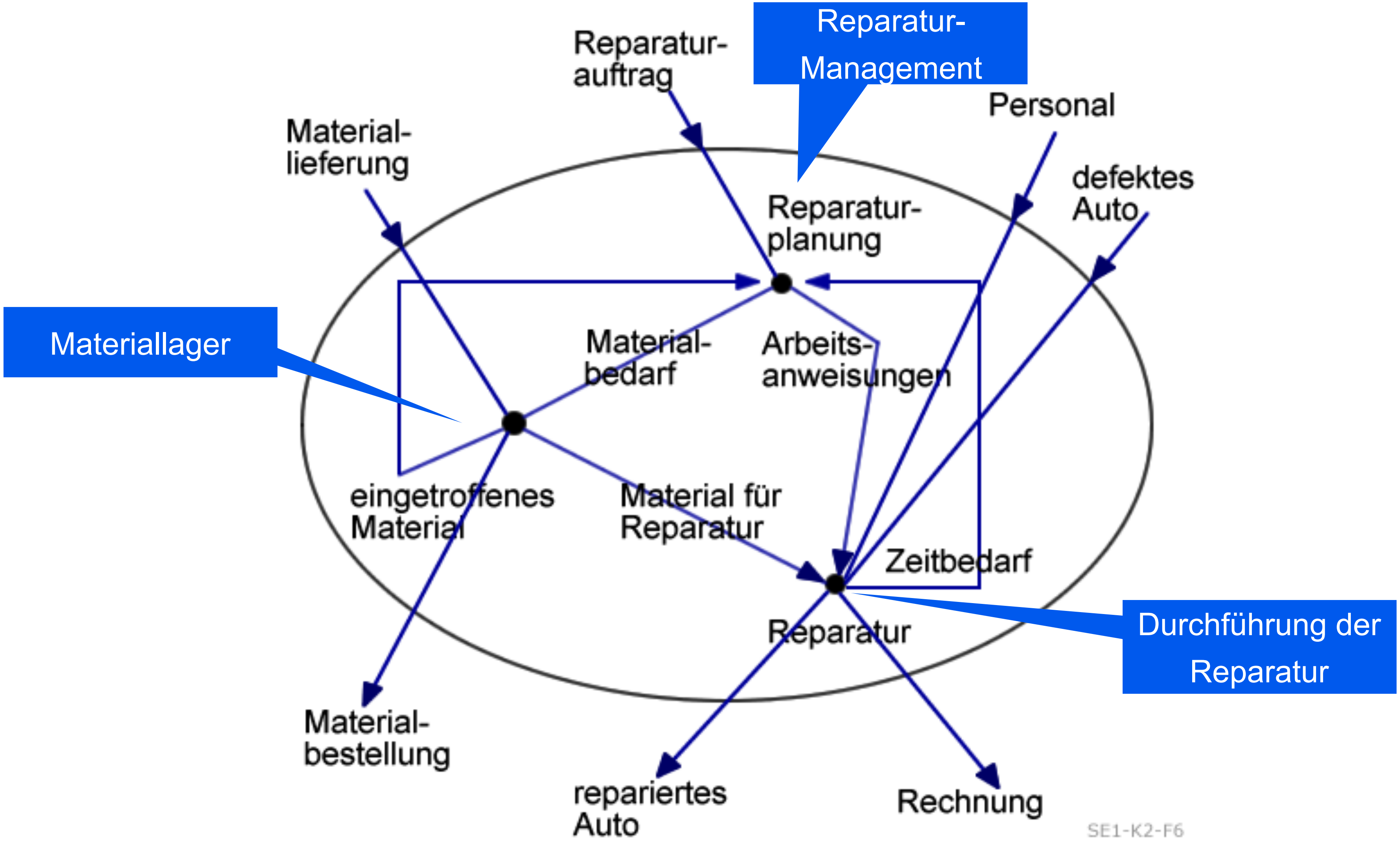
1) See also: Karl Popper: "Alles Leben ist Problemlösen" [Karl R. Popper, Piper 1996]
2) See also: Stephen Hawking, Leonard Mlodinow: The Grand Design: Model-based realism

- Abstraction is the selection and (possibly) coarsening (quantization) of certain *system characteristics* (attributes, performance indicators, parameters) from the total set of system characteristics.
- The abstraction process contains
  - simplification, → example: colour „red“
  - aggregation, → example: temperature
  - and consequently loss of information.
- The opposite of abstraction are
  - gain of information
  - detailling
  - refining
  - disaggregation
  - for engineers: design

Example: Garage



Example: Garage (microanalysis)



- Usually, the axis „abstraction <--> detailing“ is displayed vertically: high degree of abstraction vs. low degree of abstraction.

high degree of abstraction

Strongly aggregated,
no details,
only a few aspects

low degree of abstraction

detailled description,
high variety,
many different aspects

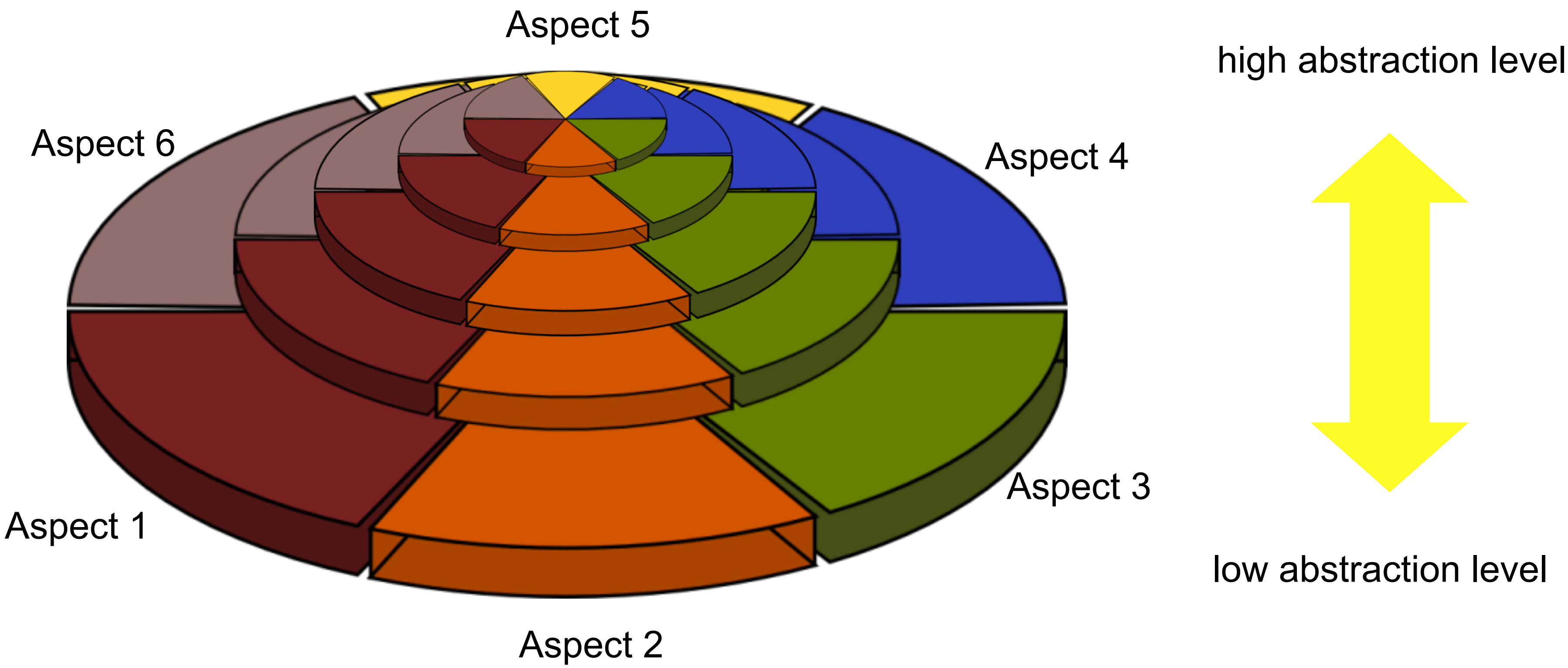
- The view on a system implies the appropriate selection of a subset of system characteristics. A defined subset is called „system aspect“ (or „view“).
- Aspects can be distinguished regarding their level of abstraction (vertical classification).

Example: Electronic system

Aspect = energy consumption

Considering the consumption of energy for different levels of abstraction:

- gate
- subsystem
- complete system

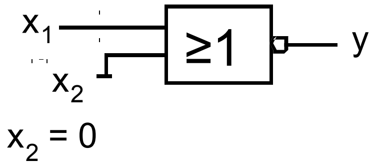

Aspect 5
Aspect 6
Aspect 4
Aspect 1
Aspect 3
Aspect 2
high abstraction level
low abstraction level

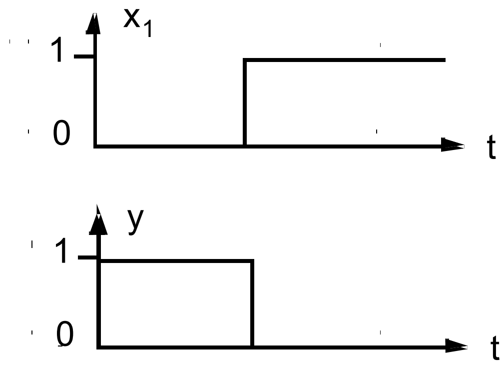
- Two important aspects of each system are:
  - structure (static) and
  - behavior (dynamic)

Example for abstraction: NOR-Gate

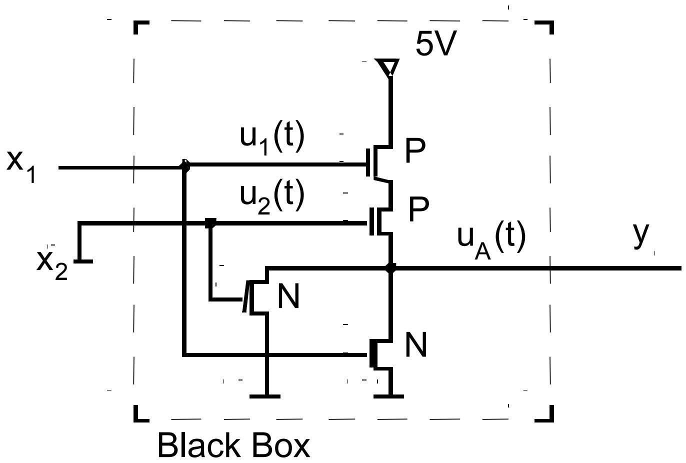
Structure | **Behavior**

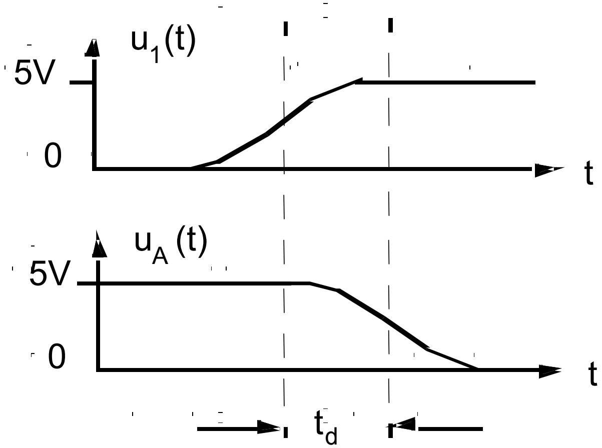
Level n



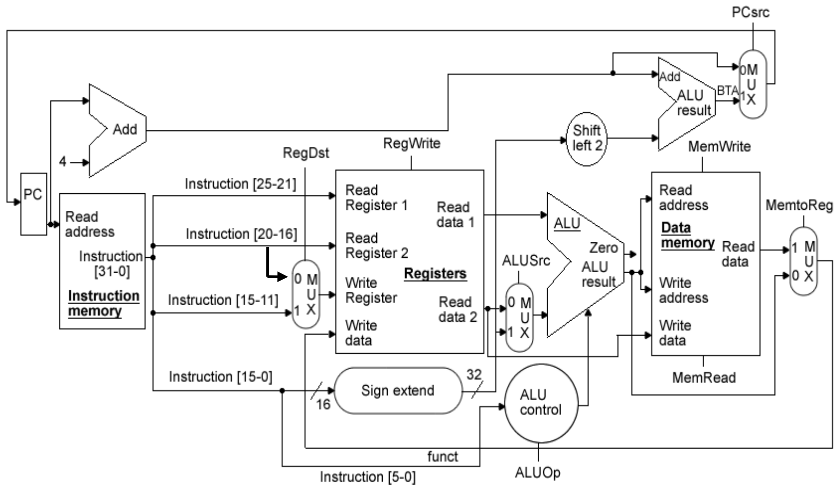


Level n-1

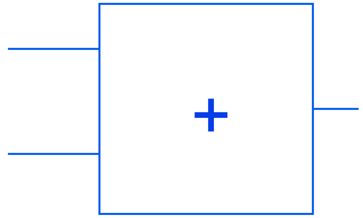




- ❑ Elements of a system are not isolated. There are various relations between the elements.
- ❑ The set of relations between elements in combination with the elements is called structure of a system.
- ❑ In simple cases the structure can be coded using the relation matrix or structure matrix (R) (also: adjacency matrix).
  - The relation matrix R of a system with n elements consists of n x n matrix elements. R is called diagonal symmetric, if the relations are not directed.
  - If a relation exists between element i and element j: $r_{ij} = 1$, otherwise $r_{ij} = 0$.



- External structure Layer 0:



- External behavior Layer 0:

  Process the machine command ADD:

  R1 ← R2 + R3

- Internal behavior Layer 0:

  Fetch instruction from main memory.

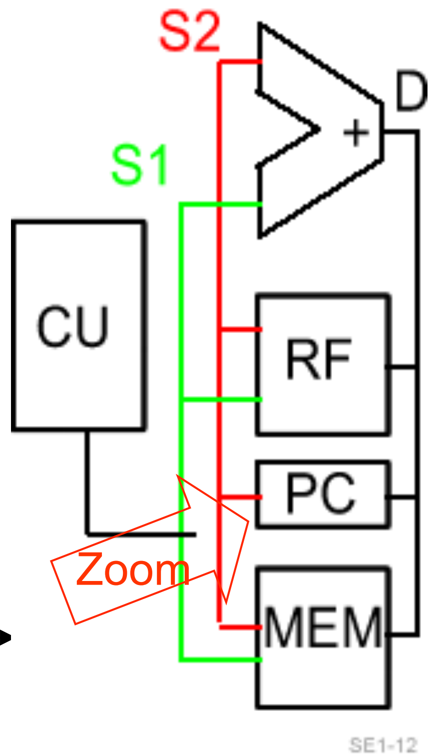
  Decode instruction

  Read register R2, R3

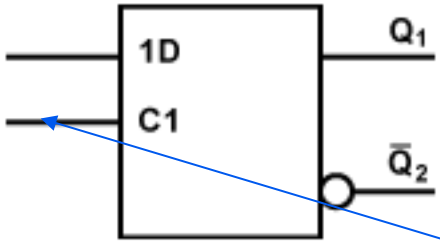
  Add

  Store result to R1

Internal structure Layer 0:



- External behavior Layer 1 (zoom to Program Counter PC):



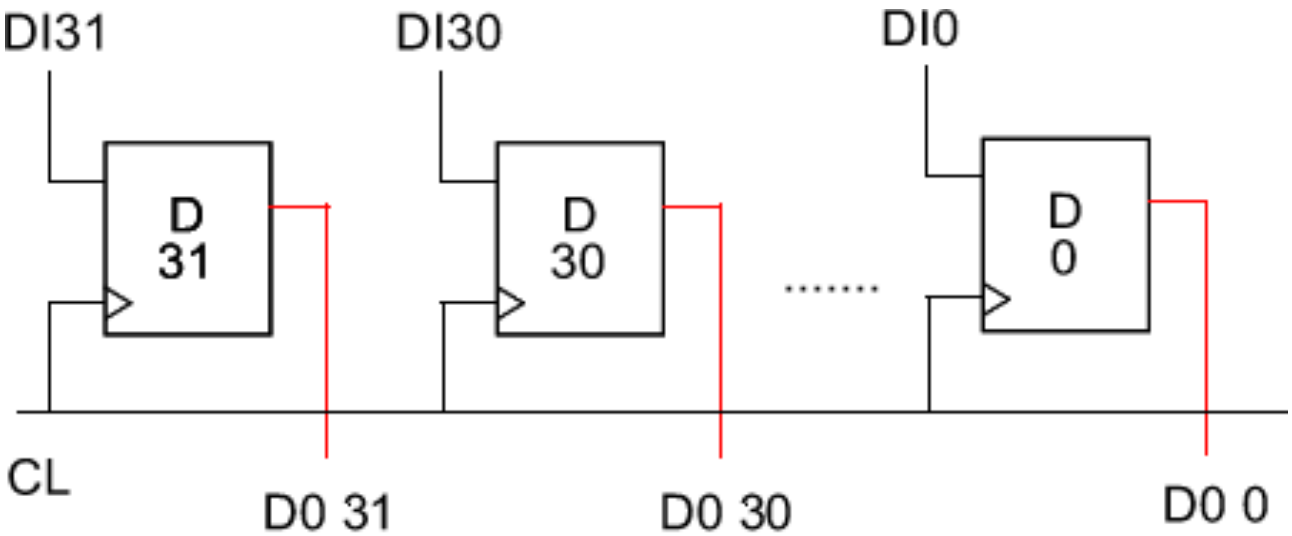
external structure

Wahrheitstabelle

E/1D	T/C1	Q_1	Funktion
0	0	n	Speichern
0	1	0	Rücksetzen
1	0	n	Speichern
1	1	1	Setzen

external behavior

- Internal structure Layer 1 (PC):



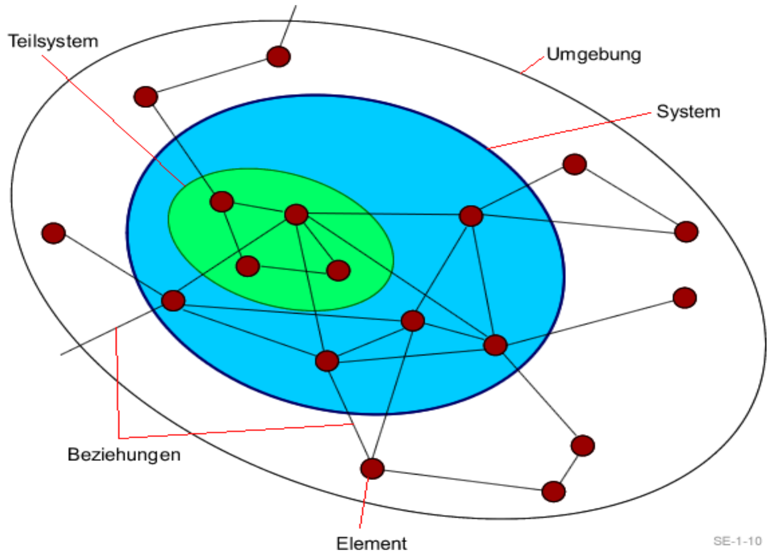
and so on…

SE1-14

- Internal behavior Layer 1 (PC): Register Transfer representation (not considered here...)

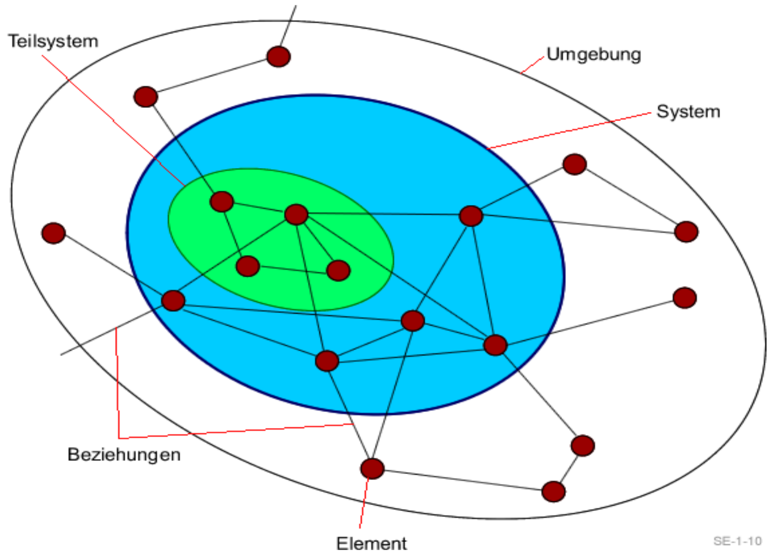
ISE SRA

- A pragmatic abstraction of systems requires the determination of relevant subsystems and supersystems (hierarchy, systems of systems).
- A subsystem is (from the engineering point of view) the system to be developed or to be analyzed. It is called the „System-under-Test“ (SuT) or System under Observation and Control (SuOC)[1].
- Entities not being part of the system belong to the environment.

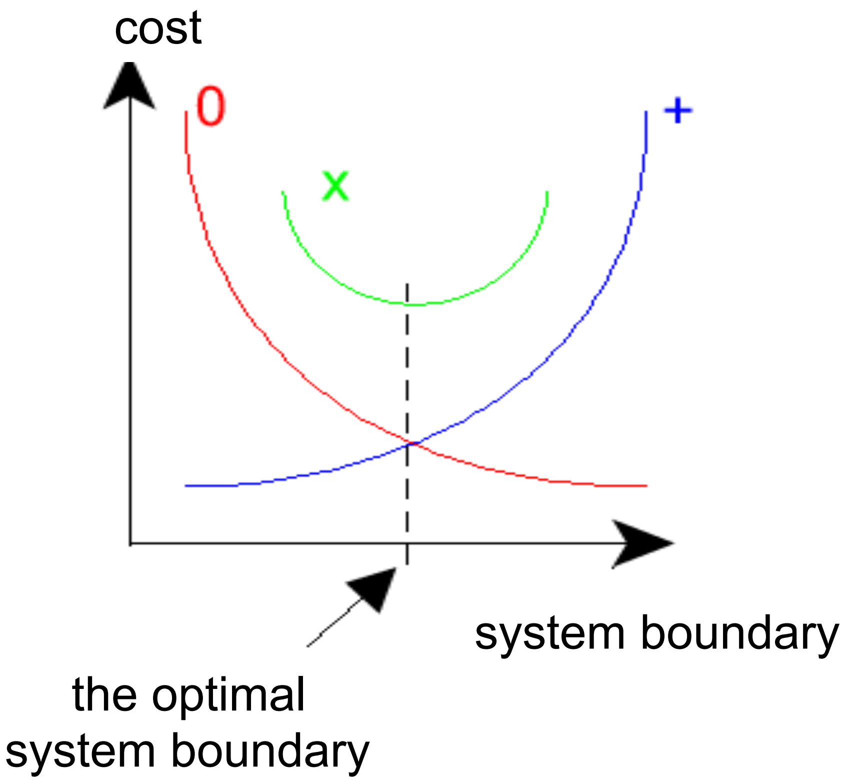


[1]) For Organic Computing we use the term SuOC instead of SuT.

- Different degrees of abstraction can be used for SuOC and environment: Different abstraction levels and different aspects might be applied.
- The border between SuOC and environment is called system boundary.
- The observer defines the system boundary for a particular purpose. It is the result of a compromise between cost and utility.



System boundary (2)



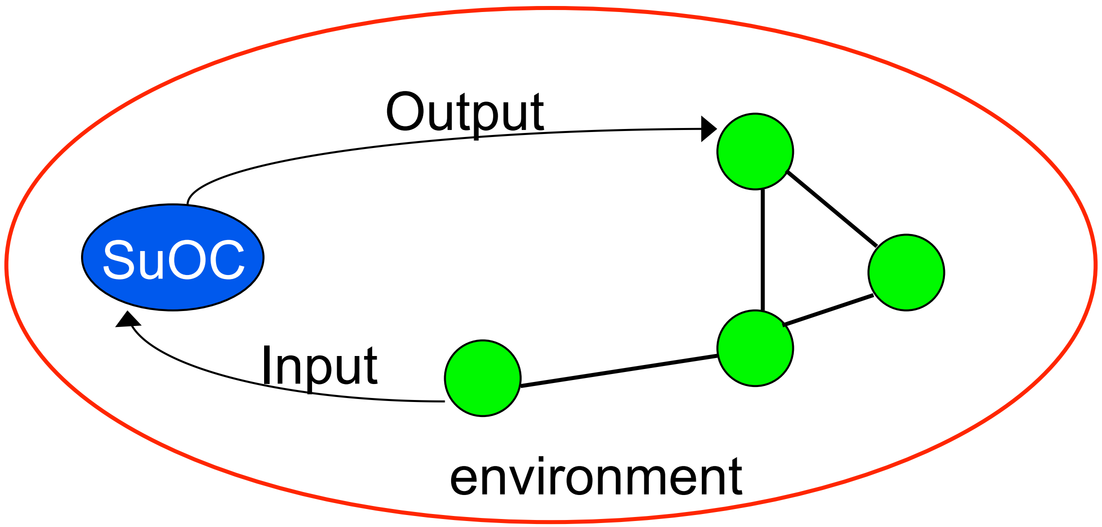
0 cost for subsequent adaptation of the system and a consecutive extension

\+ cost for planning and development

x total cost

SE1-5

- Usually, systems are interacting with their environment (open systems).
- Closed systems exist only as an approximation!
- Open systems react on inputs from the environment, and they influence the environment using outputs.
- Due to the interconnection via the environment, this leads always to a feed-back system!



- Usually, systems are transient: They change over time. They are
  - developed,
  - assembled or modified,
  - destroyed.
- Natural systems are adaptive: They continue to develop in a self-organized way (they evolve). They have to survive within a dynamically changing environment although they are subject to disturbances.
  --> cf. Robustness

❑ Loose definition

- This means: Systems react on inputs (events, signals, sensor data) by applying outputs (events, control signals, commands) to the environment.
- All open systems are reactive!

❑ More focused definition

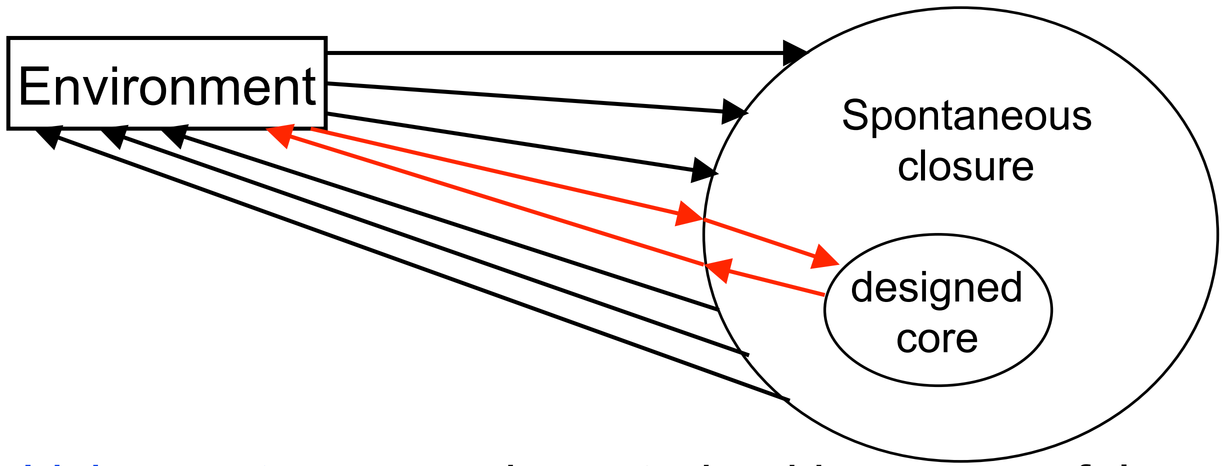
- Only systems reacting in real time (within a predefined time) are reactive systems (see: „Embedded Control").

❑ Real-time systems are characterized by

- Time restrictions (deadlines)
- Time-determinism

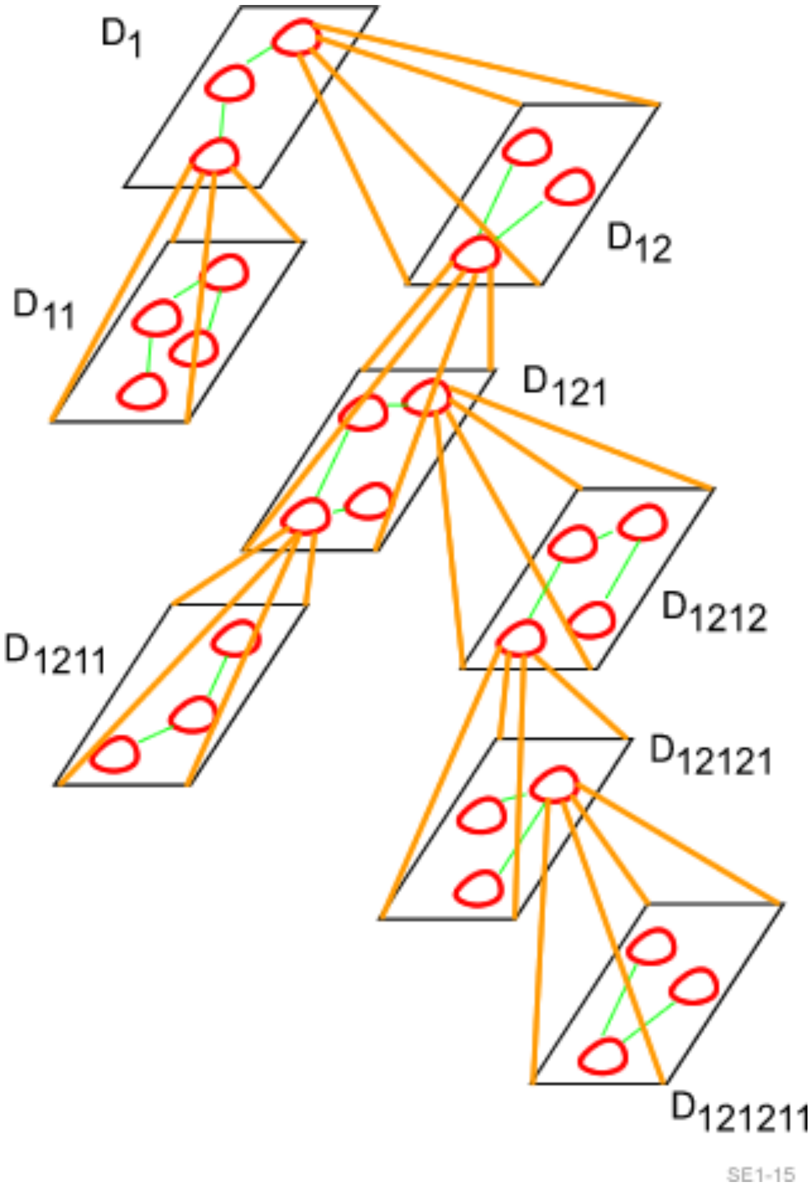
Very hard to guarantee

- During the development process of technical systems, only predictable events are taken into account.
- But: There will always be an unpredictable rest. Therefore, the „spontaneous closure“ has to cover these events.
  - Spontaneous closure in technical systems: Exception Handler, diagnosis system.



- Assumption: Living systems are characterized by a powerful spontaneous closure. Recurring reactions of the spontaneous closure become part of the designed core (learning).

hierarchy = tree



- A system is a complex whole consisting of parts. It depends on the observer, if something is considered as part or as system.
- If a subsystem is considered (!) to have a higher position (because of the aggregation) than its elements or sub-elements, the result is a layered classification (hierarchy).
- Hierarchy is a sociological (in fact theological) term, which is used to express the proportion of power. For technical systems useful!
- Problem: A hierarchy classifies a system based on a particular defining argument. Usually, more than one different classification is possible.

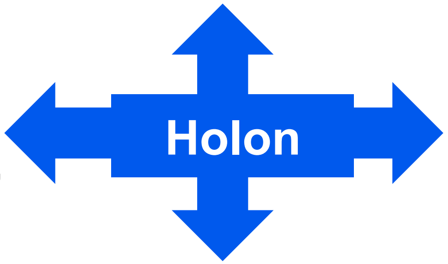
- Close inspection and analysis of nature shows:
  Each entity is both – part and whole!
- If we want to emphasize this aspect of reality, we use the term holon. Holons are not organized in hierarchies, but in holarchies (A. Koestler[1]).
- A holon shows 4 tendencies:

Janus

[1]) Arthur Koestler:
The Ghost in the Machine
Arkana 1967

higher organization,
emergence

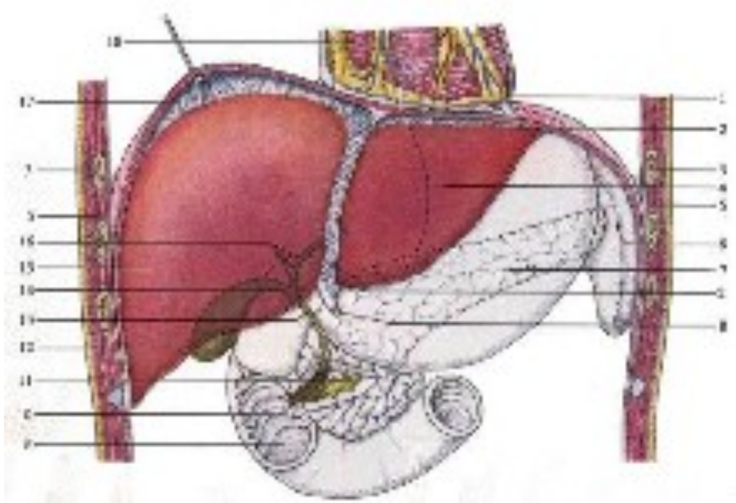
Self-protection,
self-preservation,
conservation of completeness,
concurrency, egoism



communion, cooperation,
integration into a community,
altruism

decomposition,
liquidation, death

Holarchy: Example „liver“



Forming organs: liver

Maintenance of cell functions

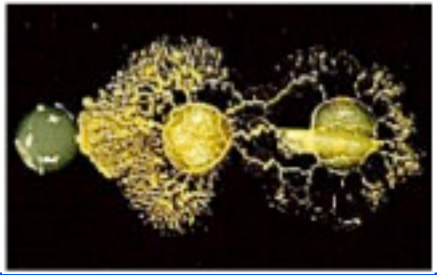
Liver cell

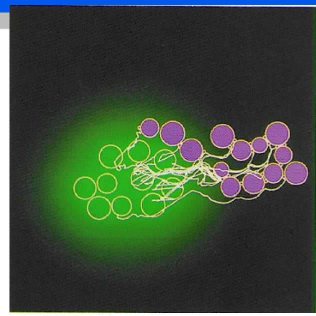
Interaction with the environment

Death

12) Level of ecosystems (total biosphere)
11) Level of populations of metazoa and plants
10) Level of metazoa and multicellular plants
9) Level of tissues and organs
8) Level of populations of unicellular organisms
7) Level of cells and of unicellular organisms
6) Level of organelles (and perhaps viruses)
5) Liquids and solids (crystals)
4) Molecules
3) Atoms
2) Elementary particles
1) Sub-elementary particles
0) Unknown: sub-sub-elementary particles?


Gaia


Slime mould Physarum polycephalum
https://www.youtube.com/watch?v=bkVhLJLG7ug


Cell structures (sim.)

[1]) See also: Popper, Eccles: „The self and its brain", p. 17, 1983 Routledge

- (High) complexity is NOT equivalent to a large number of elements within a system!
- Complexity describes the variety and dissimilarity of
  - the system‘s elements,
  - the relations between the elements (elements + relations = structure!),
  - and the functions and behavioral repertoire of elements and subsystems.
- A system with high internal complexity doesn‘t necessarily have to be complex from the external view: reduction of complexity!
- Reduction of complexity is a central objective of Systems Engineering (-> hierarchy!) and Organic Computing.
- O-Notation („big-O“, Landau-symbols): algorithmic complexity, not useful for the complexity considered here!

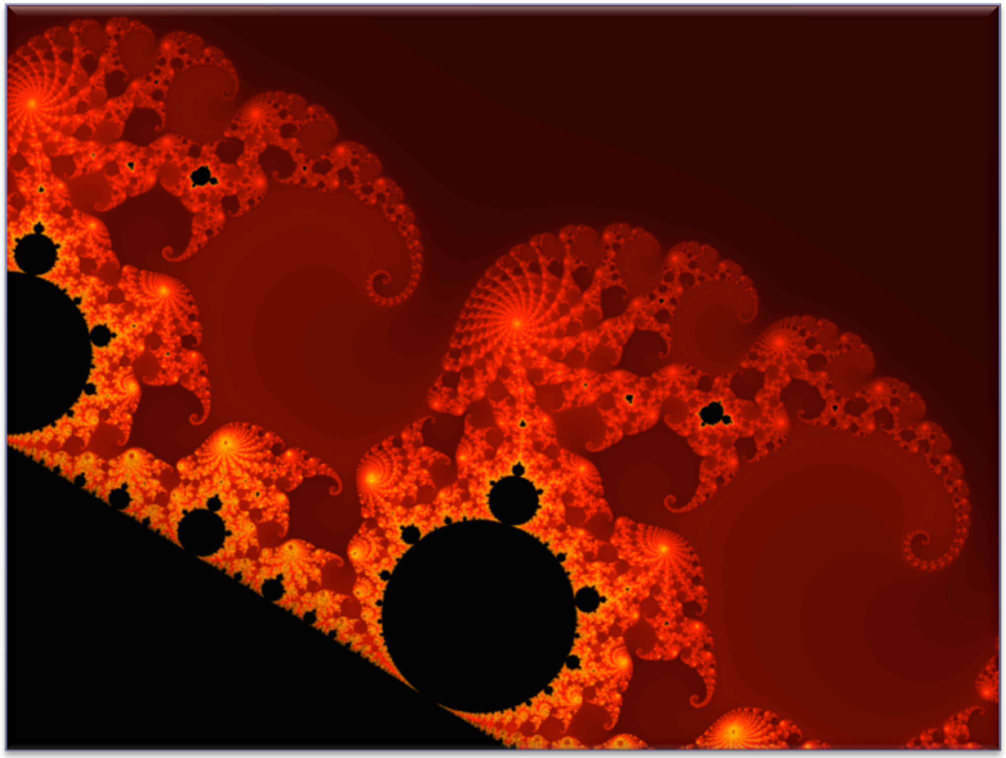
see also: Kolmogorow-Complexity

- The Kolmogorow Complexity (introduced by Andrei Nikolajewitsch Kolmogorow) is a measure for the degree of structure within character strings. It is defined as the length of the shortest program, which can generate this character string.
- Consequently, this shortest program defines the best compression of the character string without loosing information.
- The Kolmogorow Complexity is also called algorithmic complexity or description complexity.
- Example 1
  - abababababababababababababababababababababababababababababab ab → 32x ab
  - 4c1j5b2p0cv4w1x8rx2y39umgw5q85s7uraqbjfdppa0q7nieieqe9noc4cvafzf → shorter description?

❑ Example 2: Mandelbrot set

- Storing 24-bit color of each pixel in this image would require 1.62 Mbit.
- Escape time algorithm:

```
For each pixel (Px, Py) on the screen, do:
{
  x0 = scaled x coordinate of pixel (should be scaled to lie
somewhere in the Mandelbrot X scale (-2.5, 1))
  y0 = scaled y coordinate of pixel (should be scaled to lie
somewhere in the Mandelbrot Y scale (-1, 1))
  x = 0.0
  y = 0.0
  iteration = 0
  max_iteration = 1000
  while ( x*x + y*y < 2*2  AND  iteration < max_iteration )
  {
    xtemp = x*x - y*y + x0
    y = 2*x*y + y0
    x = xtemp
    iteration = iteration + 1
  }
  color = palette[iteration]
  plot(Px, Py, color)
}
```



Definition of „complexity“ given by H. A. Simon

- A complex system consists of a large number of elements, which are interacting in a non-trivial way.
- "Non-trivial interaction": One can NOT infer from the knowledge about characteristics and behavior of elements that a system will show specific properties, behavior, and characteristics itself.
- --> Complex systems have emergent properties.

Simon, H.A. (1996). *The Sciences of the Artificial (3rd ed.)*. Cambridge, MA: The MIT Press.

Herbert Alexander Simon (June 15, 1916 – February 9, 2001) was an
American political scientist, economist, sociologist, and psychologist.
Nobel Memorial Prize in Economics "for his pioneering research into the decision-making process within economic organizations" (1978).

ISE SRA