On the Notion of a System

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What is a System?

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A *system* is a set of elements that are interconnected and interact with each other, forming a unified whole that possesses properties that are not already contained in the constituent elements considered individually.

TRIZ Ontology Project

The necessity of the use of the term "system" occurs when it is required to emphasize that something is large, complex, immediately not wholly comprehensible, but at the same time a unified whole.
Unlike the notions "set" or "aggregate", the concept of a system emphasises the ordering, the integrity, the regularity of construction, functioning and development.

What is a System?

English Wikipedia on System Engineering

At its core, systems engineering utilizes systems thinking principles to organize this body of knowledge.
The individual outcome of such efforts, an engineered system, can be defined as a combination of components that work in synergy to collectively perform a useful function.

In all these definitions, the *structuredness* and thus *decomposability* of the system in the analytic dimension is emphasised on the one hand, and the *interdependence* and thus *indecomposability* in the execution dimension on the other.

What is a System?

In the assembled system in addition to the components, the *connecting elements* also play an important role. They mediate the *flow of energy, material and information* that is required for the operation of each component.

Viable components deliver processual services in *guaranteed* quantity and quality during operation, if the *external operational conditions* are guaranteed.

These processual services of the components altogether in combination form the emergent function of the overall system.

Self-similarity of the concept

Components can be considered as systems, where the upper system guarantees the required for operation throughput of energy, substance and information.

What is a System?

System concept as description of complicated real-world phenomena by reduction to the essentials.

(1) Outer demarcation of the system against an *environment*, reduction of these relationships to input/output relationships and guaranteed throughput.

(2) Inner demarcation of the system by combining subareas to *components*, whose functioning is reduced to "behavioural control" via input/output relations.

(3) Reduction of the relations in the system itself to "causally essential" relationships.

What is a System?

Such a reductive description (explicitly or implicitly) exploits output from prior life:

(1) An at least vague idea about the (working) input/output services of the environment.
(2) A clear idea of the inner workings of the components (beyond the pure specification).
(3) An at least vague idea about causalities in the system itself, that precedes the detailed modelling.

System, Components, Reuse

For technical systems additionally the aspect of reuse plays an important role.

This does not apply, at least on the artifact level, to larger technical systems – these are unique specimen, even though assembled using standardised components.

Use of components produced by third parties (components off the shelf) is widespread in developed engineering.

This ultimately turned the manufacturing of tools and products from an art first to a craft and later to an industrial process.

Hence the *production by independent third parties* and thus the technical-economic interrelationships of an industrial mode of production based on the division of labour are to be considered.

System, Components, Reuse

In such a context, the concept of a technical system is fourfold overloaded.

A technical systems can be considered

1. as a real-world unique specimen (e.g. as a product or a service),
2. as a description of this real-world unique specimen (e.g. in the form of a special product configuration)

and for components produced in larger quantities also

3. as description of the design of the system template (product design) and
4. as description and operation of the delivery and operating structures of the real-world unique specimens of this system produced according to this template (as production, quality assurance, delivery, operational and maintenance plans).

Socio-Technical Systems

Systems and social practices of cooperatively acting people.

Systems and purposes. Useful functions.

Problematisation of purposefulness (Zweckmäßigkeit) in "natural", in particular socio-ecological systems.

Purposefulness ...

... transforms the totality of technical systems into an interconnected *world of techical systems* full of preconditions and conditionalities, which opens up a fourth dimension of the concept of system, to secure stable operating conditions of the systems themselves.

Socio-technical systems are, in addition to technical restrictions, charged with the contradictory expectations and interests of concrete people and groups of people.

Socio-Technical Systems

Ian Sommerville *Software Engineering* elaborates a number of challenges in this regard.

Technical computer-based systems

... are systems that contain hardware and software components, but not procedures and processes. ... Individuals and organizations use technical systems for specific purposes, but knowledge of that purpose is not part of the system.

Socio-Technical Systems

Socio-technical systems

… contain one or more technical systems, but beyond that – and this is crucial – the knowledge of how the system should be used to achieve a broader purpose.

This means that these systems have *defined work processes*, *human operators* as integral part of the system, are *governed by organizational policies* and are *affected by external constraints* such as national laws and regulations.

Essential Characteristics of Socio-Technical Systems

- They have special properties that affect the system as a whole, and are not related to individual parts of the system. These special properties depend on the system components and the relationships between them. Because of this complexity, the system-specific properties can only be evaluated when the system is composed.
- They are often not deterministic. The behaviour of the system depends on the human operators and on other people who do not always react in the same way. Also, the operation of the system can change the system itself.

Essential Characteristics of Socio-Technical Systems

- The extent to which the system supports organizational goals depends not only on the system itself. It also depends on the *stability of the goals*, the relationships and *conflicts between organizational goals*, and how people in the organization *interpret those goals*.

In this context, there is a clear shift on the scale of controllability from direct control by external human operators to indirect control and movement according to intrinsic laws, which is even more prevalent in **socio-economic systems** with a large number of stakeholders or even **socio-ecological systems**.

Shchedrovitsky on Systems Analysis

The system concept serves to delimit a part of the complex, all-connected world (*reality*) in order to make this part accessible for description.

However, this human activity, which Georgi Shchedrovitsky (a Russian Philosopher and the head of the *Methodological School of Management*) refers to as *mental activity* (Denktätigkeit), is itself part of that reality and thus also of practical relevance. Real-world processes are thereby charged with description forms.

Thus in system theory these two dimensions – description and operation – must be distinguished. Charging a system with a description form is what Engels' calls, in reference to Kant's *thing in itself*, the transformation of the *thing in itself* into a *thing for us*.

This concept is developed by Shchedrovitsky in greater detail.

Theory of Dynamical Systems

The processual dimension of systems can be investigated with the mathematical tools of the Theory of Dynamical Systems if the processes can be modelled as equations of motion in phase space.

Phase space and equations of motion. Notion of trajectory.

Examples:

- Pendulum:
  `https://en.wikipedia.org/wiki/Pendulum_(mechanics)`
- Two body problem:
  `https://en.wikipedia.org/wiki/Two-body_problem`

How Chaotic can Trajectories be?

Examples:

- Double Pendulum,
  `https://en.wikipedia.org/wiki/Double_pendulum`
- Magnetic pendulum with three attracting magnets,
- 3-body model:
  `https://en.wikipedia.org/wiki/Three-body_problem`

Not everything that looks like chaos has to be chaotic:
`https://i.redd.it/zr7tet9mdfl01.gif`

Attractors

Examples:

- Pendulum,
- pendulum with three attracting magnets,
- pendulum with one repelling magnet.

Limit cycles: `https://en.wikipedia.org/wiki/Limit_cycle`

When the body is on the limit cycle, it remains there, i.e. the limit cycle is a *stable solution* of the equations of motion of the system, called **steady-state equilibrium**.

Attractors

In many cases the real movement $f(t)$ in time is *attracted* by that limit cycle, i.e. $f(t)$ can be decomposed into $f(t) = l(t) + r(t)$ with $l(t)$ the projection on the limit cycle and $r(t) \to 0$ a (small) orthogonal deviation. In this way, it is often possible to simplify complicated models.

An **attractor** is a specific steady-state equilibrium with just this attracting property.

`https://en.wikipedia.org/wiki/Attractor`

How Complicated can an Attractor be?

- https://en.wikipedia.org/wiki/Attractor
- https://en.wikipedia.org/wiki/Lorenz_system
- https://de.wikipedia.org/wiki/Lorenz-Attraktor
- "Almost all initial points will tend to an invariant set – the Lorenz attractor – a strange attractor, a fractal, and a self-excited attractor" (Wikipedia)

Dissipative Systems

Closed and Open Systems

Relation between a (stable) external throughput of energy, matter and information and the inner structure formation in systems.

- https://en.wikipedia.org/wiki/Rayleigh-Benard_convection
- https://en.wikipedia.org/wiki/Belousov-Zhabotinsky_reaction
- Dissipative systems https://en.wikipedia.org/wiki/Dissipative_system
- Life on Earth as a dissipative system.