# THE INTEGRATION CHALLENGE FOR THE SYSTEMS SCIENCES: HIGHLIGHTING INTERNAL AND EXTERNAL INTERCONNECTIONS

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## ABSTRACT

Systems science is concerned, among other things, with functional wholes, interactive parts and exchange with the systems environment. What does it mean to observe systems science itself with respect to these aspects? What function does systems science have within the landscape of sciences? What do the various systemic sub-disciplines contribute to a united systems science?
In this paper the following will be attempted:
Indicating a set of interrelated system principles. Using this set to clarify the special characteristics and contributions of the sub-disciplines of systems science; and localizing systems science within the landscape of sciences and indicating relevant connections.

Keywords: systems science, philosophy of science, interdisciplinarity, maps, sub-disciplines, system principles, system types, system classes, systems thinking, systems thinkers

## 1. INTRODUCTION

Over the past two decades one can ascertain growing interest in systemic approaches in the fields of counseling and management. Approaches such as systemic coaching, systemic organization counseling or systemic leadership have increased in significance.[1]
In many other cases systemic concepts are tacitly employed without any reference to the sources, as the concepts are evidently known and familiar to everyone: system, complexity, feedback, etc. But how can interested persons gain an overview and deeper understanding of the spectrum of systems science[2] as a whole and its place and function in the larger landscape of the science system?
Bertalanffy (1956) summarizes the aims of a general theory of systems as follows:

a) There is a general tendency toward integration in the various sciences, natural and social.
b) Such integration seems to be centered in a general theory of systems.
c) Such a theory may be an important means of aiming at an exact theory in the nonphysical fields of science.
d) Developing unifying principles running "vertically" through the universe of the individual sciences, this theory brings us nearer to the goal of the unity of sciences.
e) This can lead to a much-needed integration in scientific education.

[1] Various publications in the last two decades show the influence of systems and complexity thought in many domains of counseling and management, for example: Senge (1990), Gharajedaghi (1999), Ulrich (2001), Malik (2002), Jackson (2003).

[2] Klir (2001): "Systems science is a science whose domain of inquiry consists of those properties of systems and associated problems that emanate from the general notion of systemhood."

Nevertheless various problems have up to now limited a further spread of this kind of systems knowledge.[3] Some argue that systems science gives the impression of a broad but still unstructured field. The many schools of thought within the systems approach that have developed over the decades provide different viewpoints, but also make it more difficult to master the field as a whole. The abstract language and concepts that have been developed can make it hard to understand. For educational purposes, additional overviews of the field, its authors and core principles are still needed.

The motivation for this article is to make the fundamentals of systems thinking more approachable to researchers outside the field of systems science and persons practically involved in education, counseling or management. In addition, an integrative approach will be used here. In comparison with other descriptions, certain new forms of visualization and classification were used here in order to highlight internal and external interrelationships and aid general understanding.

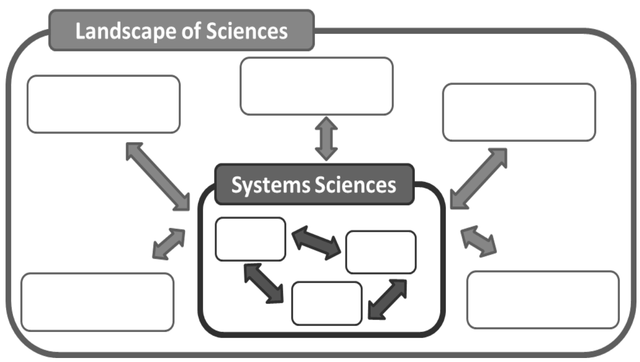


**Figure 1: Relations of systems sciences in the landscape of sciences. How can science be organized – from a systemic viewpoint? How can systems science be understood and classified – from the viewpoint of the sciences as a whole?**

## 2. DEFINITION OF SYSTEM

> *"The concept of a system is one of the most widely used concepts in science, particularly in recent times. It is encountered in nearly all the fundamental fields of science, e.g., in physics, chemistry, mathematics, logic, cybernetics, economy, linguistics, biology, psychology, and also in the majority of engineering branches." Klir (1965)*

What is a system? Although the concept of a system is now very widespread, we still have a situation where multiple definitions co-exist. Some understand systems as the simplest form possible (see the figure at the left below). "A system is a set of objects together with relationships between the objects and between their attributes" Hall & Fagen (1956). Others connote with the word system a relatively complex adaptive system, which has many interrelated subsystems and is once again a part of a larger system (see the description at the right below). "CAS [Complex adaptive systems] are systems that have a large number of components, often called agents, that interact and adapt or learn" Holland (2006).

[3] Several authors have mentioned critical aspects of the systems movement, such as Phillips (1969); Troncale (1985); Müller (1996).

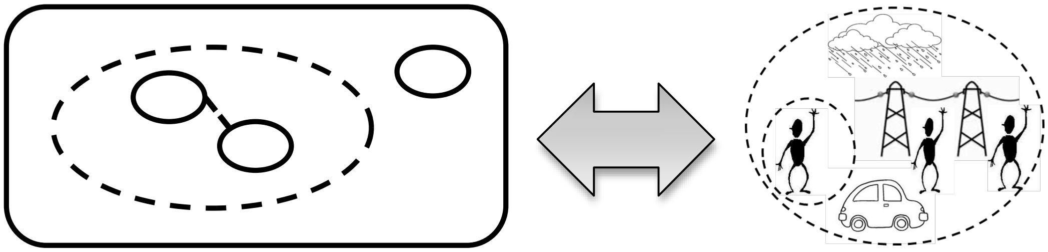

**Figure 2: Two illustrations of a system. Left: a minimal system; right: an adaptive agent interacting with his changing environment.**

## 3. FIVE GENERAL SYSTEM CLASSES

Although the concept of system can be used for almost anything, we can make a division into various large categories of systems as they exhibit clearly varied qualities. Several authors have described a range of general system classes.[4] The following table makes a division into five different classes. They are differentiated from each other on a horizontal line. On the right, to begin with, are the non-living natural systems. Non-living natural systems, such as atoms and molecules, are the basis of biological systems. Cognitive systems (i.e., systems capable of cognition) are composed of biological systems. The human being probably has the most highly developed cognitive system. A cognitive system includes consciousness, ideas, thoughts, perception and an ego-perspective. It is the prerequisite for communication. On the basis of communication are built social systems such as working groups, tribes and peoples. Another expression of human culture is the creation of products, such as tools, houses, means of transportation, means of communication, energy supply. To these five different system classes we can assign research fields, as shown in the table. It should also be noted, however, that there are many research fields that combine several such classes. In the field of ecology, for example, both non-living and living systems are observed. In the field of health research one can speak in terms of a bio-psycho model of human health. Companies are understood as socio-technical systems.

**Table 1: Overview of some classes of systems (Hieronymi, Draft)**

| | older ⟷ | | | | newer |
|---|---|---|---|---|---|
| | **Non-living natural systems** | **Biological Systems** | **Cognitive Systems** | **Social Systems** | **Technical Systems** |
| Examples | Solar System<br>Crystal<br>Avalanche<br>Tornado<br>Clouds … | Cells<br>Tissues<br>Organs<br>Body … | Higher developed animals<br>Man<br>Mind … | Couple<br>Family<br>Team<br>Company<br>City, Nation<br>… | Car<br>Mobile phone<br>Internet<br>Robot … |
| Research fields | Physics, Chemistry … | Biology … | Psychology … | Sociology, Economy … | Engineering … |

[4] Luhmann (1987) discerns four types of systems: machines, organisms, social systems and psychic systems. Similar classes: McPherson (1974), Henriques (2003).

## 4. PRINCIPLES OF SYSTEMS

> *Today our main problem is that of organized complexity. Concepts like those of organization, wholeness, directiveness, teleology, control, self-regulation, differentiation and the like are alien to conventional physics. However, they pop up everywhere in the biological, behavioral, and social sciences, and are, in fact, indispensable for dealing with living organisms or social groups.*
> *Bertalanffy (1956)*

What do the several kinds of systems have in common? The choice of the following principles is the present result of extensive literature research by the author in multiple fields of knowledge. They also comprise a core section of his intended future research. The fields of knowledge, where similar approaches can be found, include theoretical biology (characteristics of life), psychology, sociology, management, artificial intelligence and robotics.[5]

The proposed principles are described below in the sense of a simple system evolving step by step into a more complex one. In each step, the focus is changed to an additional type of functionality or process.

- **Boundary:** Basically speaking, a system exists as a unity through the links between its elements and the **boundary** that differentiates the system from its environment; it can still be static in such a case.
- **Energy:** If a system moves and **energy** flows through it, it becomes an active system.
- **Computation:** Through the **processing and computing of relevant data** and the actions based on them, a system becomes a rule-based system.
- **Perception:** If a system is able to detect and perceive certain **signals** of its environment, such as through sensors, and uses this information in the form of **feedback**, it becomes a cybernetic system.
- **Robustness:** If a system can store energy and thus enable a longer-range task and **structure maintenance** even without a continuous flow of energy from outside, it becomes a robust system.
- **Identity:** A system becomes self-referential in referring to its own conditions of the present and past; it thereby creates an **identity** and memory and the behavior from now on might also show nonlinear, chaotic and unpredictable behavior.
- **Adaptation:** If a system attempts to maintain inner conditions that are favored, it assumes a form of homeostasis and becomes an **adaptive** system.
- **Innovation:** A system becomes a learning system when it can create new internal connections; in this sense it is enabled for **innovation** and evolution.
- **Organization:** If a system is able to control and establish future **goals that organize** its behavior and can include multiple priorities in a ranking order it becomes a goal-oriented system.

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[5] Several lists of principles of (living) systems have been proposed. They include: Ganti (2003), Koshland (2002), Brum et al. (1993), Elitzur (2005). Other lists of living systems components: Miller (1978). Technical view: Russell & Norvig (2004); Pfeifer, & Scheier (2001); Braitenberg (1993).

- **Communication:** If a system can **communicate** internal conditions and goals to other systems and prompt them to take action, it becomes a communicative system.
- **Boundary:** A system builds new boundaries when longer-lasting connections and cooperation arise from acts of communication; it becomes a social system that can build **relationships, networks, alliances, and new unities**. We have thus reached a new, higher and **emergent boundary level**. This closes the circle and the evolving process can be repeated on the next level.

Based on these principles we can as a further step describe a hierarchical classification of system types.

## 5. TYPES OF SYSTEMS

Based on the system principles described above we can now describe a hierarchical classification of system types.

Proposed system types of the author, as based on the developed principles (from bottom to top):

- 0 **Passive system** (connected elements, boundary)
- 1 **Active system** (energy flow, motion)
- 2 **Rule-based system** (data processor, rules, computation)
- 3 **Cybernetic system** (sensors, perception, feedback)
- 4 **Robust system** (energy storage, redundancy, robustness)
- 5 **Self-referential system** (identity, memory)
- 6 **Adaptive system** (internal homeostasis, adaptation)
- 7 **Evolutionary system** (creativity, innovation)
- 8 **Goal-oriented system** (goals, organization, priorities)
- 9 **Communicative system** (messages, interaction, communication)
- 10 **Social system** (communication-based boundaries, partnerships, alliances)

Other proposed system principles and types: see e.g. Boulding (1956), Ackoff (1971), Mingers (1995), Martinelli (2001). System types of organizations: Morgan (1986).

## 6. SUB-DISCIPLINES OF SYSTEMS SCIENCE

If systems science is not a homogenous field, what sub-disciplines belong to it? And how do they relate to core functions and principles of systems?

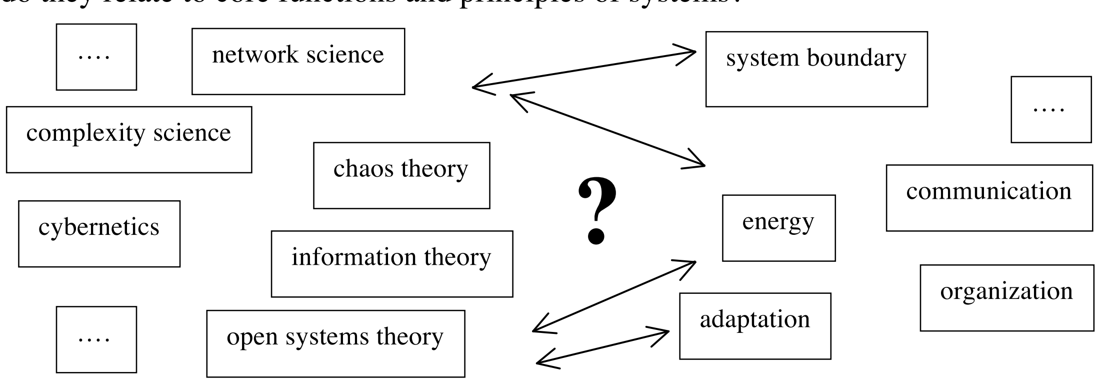


**Figure 3: Left: A range of sub-disciplines of systems science. Right: Some key principles/concepts**

It should be possible to analyze the intensity of the influence that various traditions of systems science have had to establish or clarify some of the key systemic principles. There are many historical overviews on the development of systems research (among others: François 1999; Hammond 2003; Schwaninger 2009, Merali & Allen 2011). We will focus here on the following traditions: Thermodynamics, open-systems-theory, information theory, cybernetics, theory of autopoiesis, chaos theory, complexity theory, (multi-) agent modeling, network science.

The mentioned traditions can be summarized as follows[6].

- **Thermodynamics** treated closed systems in an energetic equilibrium. Nevertheless it reached its limits in regard to systems in non-equilibrium.
- **Open systems theory** described the necessity of living systems being energetically open to the environment.
- **Information theory** treated the storing, compression and transmission of data.
- **Cybernetics** described feedback processes for ordering and controlling systems.
- **The theory of autopoiesis** clarified how living systems recreate and maintain themselves continually.
- **Chaos theory** indicated the reasons for instability and nonlinear change processes.
- **Complexity theory** described processes of self-organization, adaptation and innovation.
- Within the framework of **modeling autonomous agents** it was possible to formulate and simulate processes of systems (agents) that act in a goal-oriented manner (e.g. humans, robots).
- **Network theory**, finally, is concerned with the interaction of numerous actors, their process patterns and dynamic social structures.

A possible combination of above mentioned sub-disciplines and a set of proposed system principles (chapter 4) are provided in the table below. It should enhance communication between the different perspectives and provide a simplified but ordered overview. The rough timeline starts with thermodynamics and then encompasses around sixty years of systems science.

[6] References for the sub-disciplines of systems science: Thermodynamics: Atkins (2010); Open Systems Theory: Bertalanffy (1950); Information theory: Shannon & Weaver (1948); Cybernetics: Wiener (1948); Ashby (1956); Theory of autopoiesis: Maturana & Varela (1980); Chaos theory: Mandelbrot (1983), Gleick (1987); Complexity theory: Kauffman (1993), Kauffman (1995); Holland (1995); Multi-agent modeling: Axelrod (1997); Network Science: Barabasi (2003), Watts & Strogatz (1998), Watts (2004).

**Table 2: Sub-disciplines within systems sciences and proposed principles of systems (Hieronymi, draft). One to three stars (*) indicate a suggested correlation between the theoretical fields and the proposed system principles. This table is for illustrative purposes and is not yet based on data.**

| → *System principles (functions)* <br> *Sub-disciplines* ↓ | Time (~) | (0) System Boundary | (1) Energy | (2) Computation , Data processing | (3) Sensors , Perception, Feedback | (4) Structure Maintenance, Robustness | (5)Self-reference, Identity | (6) Adaptation | (7) Innovation | (8)Organization , Control | (9) Communication | (10) Networks, relationships, emergent boundaries |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Network Science | ~2005 | * | | | | | * | * | * | * | *** | *** |
| (Multi-) Agent Modeling | ~2000 | | | * | * | | | * | * | *** | *** | * |
| Complexity Theory | ~1985 | * | * | | | * | *** | *** | *** | * | | * |
| Chaos Theory | ~1980 | * | * | | * | * | *** | ** | * | | | |
| Theory of Autopoiesis | ~1975 | | | | * | *** | ** | * | | | | |
| Cybernetics | ~1955 | | | ** | *** | ** | | ** | | ** | ** | |
| Information Theory | ~1953 | | | *** | ** | | | | | | ** | |
| Open Systems Theory | ~1950 | *** | ** | | | ** | | ** | | | | |
| Thermo-dynamics | ~1850 | * | *** | | | | | | | | | |

Looking at the distribution of the stars (*) in the table above, we can see an emergent visual trendline: from the lower left to the upper right.
This leads to the following two hypothesis:

- **Hypothesis 1:** The development of systems science, with its various sub-disciplines, follows a rationally comprehensible process in the sense of paradigm shifts and scientific revolutions.
- **Hypothesis 2:** The development of systems science approached and clarified step by step processes and principles with increasing levels of complexity.

The prevailing sub-discipline focuses on and describes a particular viewpoint and aspect of reality. With time, however, it reaches its limits in explaining or predicting the anomalies of behavior of the system in question. This is in the sense of reduced marginal benefits with increasing system/situation complexity. In the sense of Thomas Kuhn's paradigm shift (1970), small scientific revolutions occurred here: Change in perspective, change in mental models and methods of the researchers. Often this shift is also supported by the use of more sophisticated and efficient calculation methods und computer resources.

Although there are similar assumptions already existing, systemic principles and systemic hierarchies are seldom connected to each other in such a manner as in this paper. A more comprehensive support of this assumption should be the subject of further studies.

## 7. SYSTEMS SCIENCE WITHIN THE SCIENCE SYSTEM

*"It used to be that the classification of sciences was clear. There were natural sciences, and there were social sciences. Then there were mathematics and logic …" "This neat picture has been disturbed by the appearance in the last fifty years of a number of new sciences …" Franklin (1994).*

What is the role of systems science in the landscape of theoretical and applied sciences? Where can systems science be positioned? What contributions are expected from systems science?
Boulding (1956) described "general systems theory" as "the skeleton of science". "It aims to provide a framework or structure of systems on which to hang the flesh and blood of particular disciplines and particular subject matters in an orderly and coherent corpus of knowledge." If systems science is to be assigned such an organizing and connecting role[7], this involves various challenges.
It is only when the landscape of the other science fields is precisely described that it is possible to allocate the focus of systems science. At the same time, this step requires an internal organization and outer orientation of the systems sciences.
Basically speaking, any science is concerned in a certain sense with systems. Biology is concerned with biological systems, psychology with psychological systems, etc. The factor that distinguishes systems science is the fact that it further abstracts these various system classes to work out the common elements and differences. But there is also the question of where precisely systems science is to be classified in the field of the sciences. In answer to this question two overviews are presented. The following graphic representation (Table 3) shows how general dimensions of knowledge can be organized from a systemic viewpoint.

**Table 3: Five dimensions of knowledge (Hieronymi, Draft)**

| ↕ | **Attributes** | **Dimension of Knowledge** |
|---|---|---|
| | Normative | **Ethics and esthetics** |
| | | **"Systems Design"** (Decision making, problem solving, design …) |
| | Phenomenological | **Phenomenological World**<br>(Physics, Biology, Psychology, Sociology, Technical Science …) |
| | Formal | **"Systems Science"** (General systems theory, cybernetics, information theory, complexity theory …) |
| | | **Logic and Mathematics** |

In the center are the phenomenological sciences to which belong the sciences such as physics, biology, etc. In the direction of **formal** science, **logic and mathematics** are mentioned at the other end. Between logic and mathematics and the phenomenological

[7] Klir (2001): "The cross-disciplinary orientation of systems science has a unifying influence on classical science, increasingly fractured into countless number of narrow specializations, by offering unifying principles that transcend its self-imposed boundaries. Classical science and systems science may be viewed as complementary dimensions of science".

sciences we can classify **systems science**[8] with its sub-disciplines. In the top portion of the table are **normative** sciences concerned with goals and values of society: **ethics and aesthetics**. How these goals are to be attained is a question addressed by a field still lacking a standard form. This field is concerned with general forms of decision-making, problem-solving or creation of processes and systems. It could be described as design-science or **systems-design**.[9]

The following map (Figure 4) provides an overview regarding the position which systems science could be assigned within the entire science as a whole.[10] The described horizontal system categories (Table 1) are combined with the vertical knowledge dimensions (Table 3).

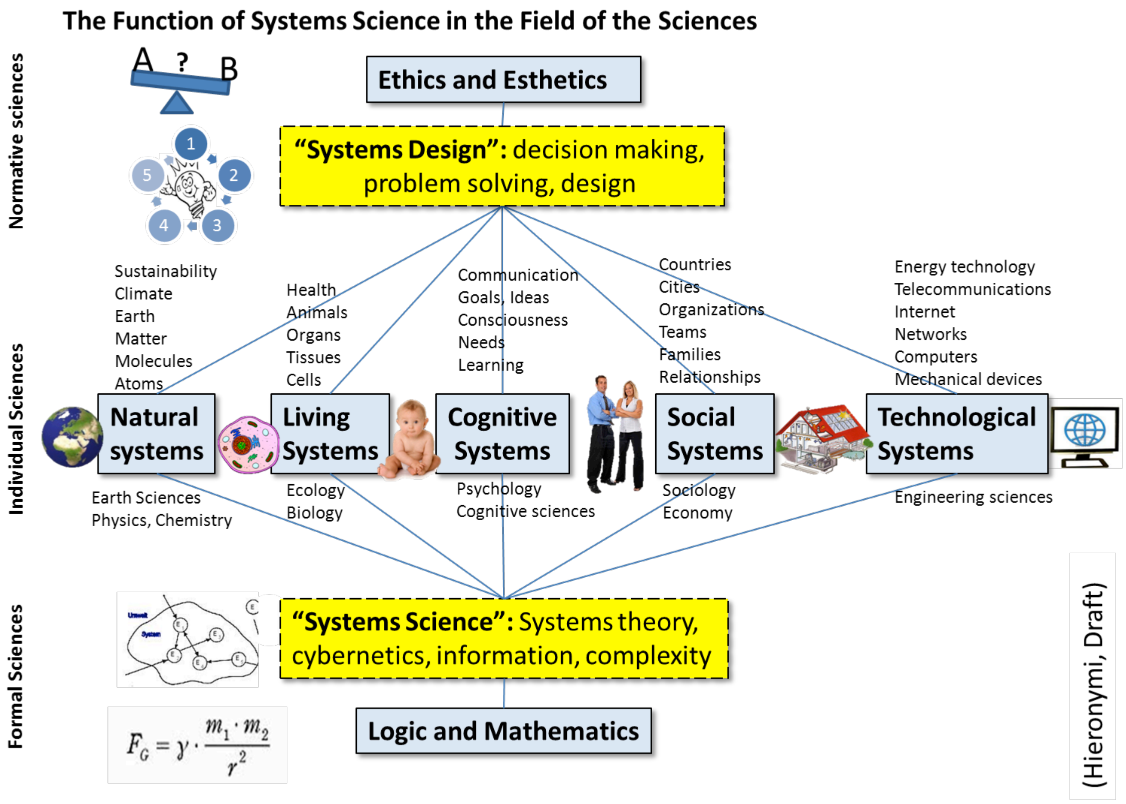


**Figure 4: Map of systems science in the landscape of the sciences (Hieronymi, draft)**

In this map there are five major individual science fields in the central level, which revolve around the concepts: **natural system, living system, cognitive system, social system, technological system**. These are encircled by further science fields: **Logic and mathematics** are often considered to be the basis of the sciences. The roof is formed by questions about **ethics** (values), **esthetics** (the beautiful), and reflection of knowledge and

[8] Boulding (1956): „**General Systems <u>Theory</u>** (…) lies somewhere **between** the highly generalized constructions of pure **mathematics** and the specific theories of the **specialized disciplines**.").

[9] "In **<u>design</u>**, we focus on finding solutions and creating things and systems of value that do not yet exist." Banathy (1996). We can distinguish between: „work aiming to develop systems ideas in the design of real-world systems" and "the purely theoretical development of systems ideas and their interrelationships" Laszlo & Laszlo (2003); similar: Banathy (1996).

[10] Other maps describing the landscape of the sciences as a whole: e.g. Müller (2011).

action. In this diagram are included two further fields: **Systems Science** is located as an abstract, formal science between mathematics and the individual sciences. **Systems Design** indicates the heterogeneous field of methods and practices, which explain how problems are best identified, how solutions are found and how the way to solutions is created strategically.
Systems science and its interdisciplinary concepts and language provide a bridge between science and the humanities, between descriptive research and normative practice, thus making a contribution to the unity of knowledge.[11]

## 8. SYSTEMS THINKING AND SYSTEMS THINKERS

*"Systems thinking is often defined by its contrast to the Cartesian paradigm which is characterized by the belief that the behavior of the whole can be understood entirely from the properties of its parts." Merali & Allen (2011)*

What characterizes a systems thinker? There are at least two possibilities: The person works in the field of systems science; the person thinks and works with systemic-oriented approaches and systemic methods, regardless of what kind of object is involved. Even when it is not concerned with the same object: Systemic thinkers often consider multiple perspectives and ask various questions, according to their perspective or the existing circumstances.

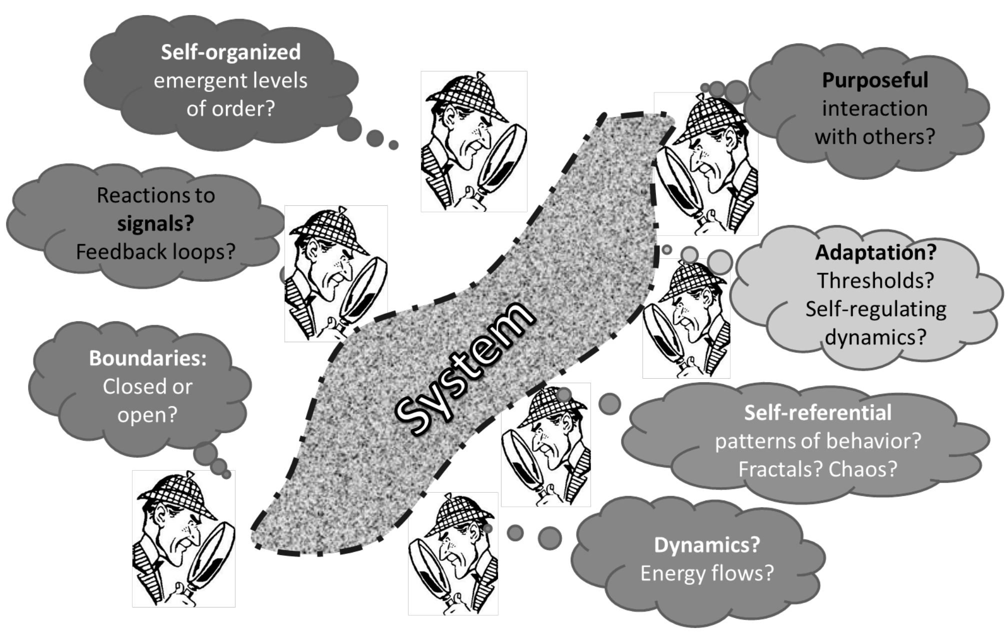


**Figure 5: Systemic thinkers in action. This picture shows how the same system can be examined from different perspectives while posing different questions. (Hieronymi)**

We now provide a short overview of individual systems thinkers.[12] A special feature of the systems movement is the fact that many of its important exponents come from very

[11] Bailey (2001) "Unified science has long been a major goal of the systems movement". See also Bertalanffy (1968); Boulding (1956).

different science fields. The systemic authors, in other words, are interdisciplinary in their own fields. One could almost say that there are as many systemic approaches as there are systems scientists! The descriptions of systems views are often colored by the original specialty of the author in question. This becomes understandable when one examines the graphic representation below.

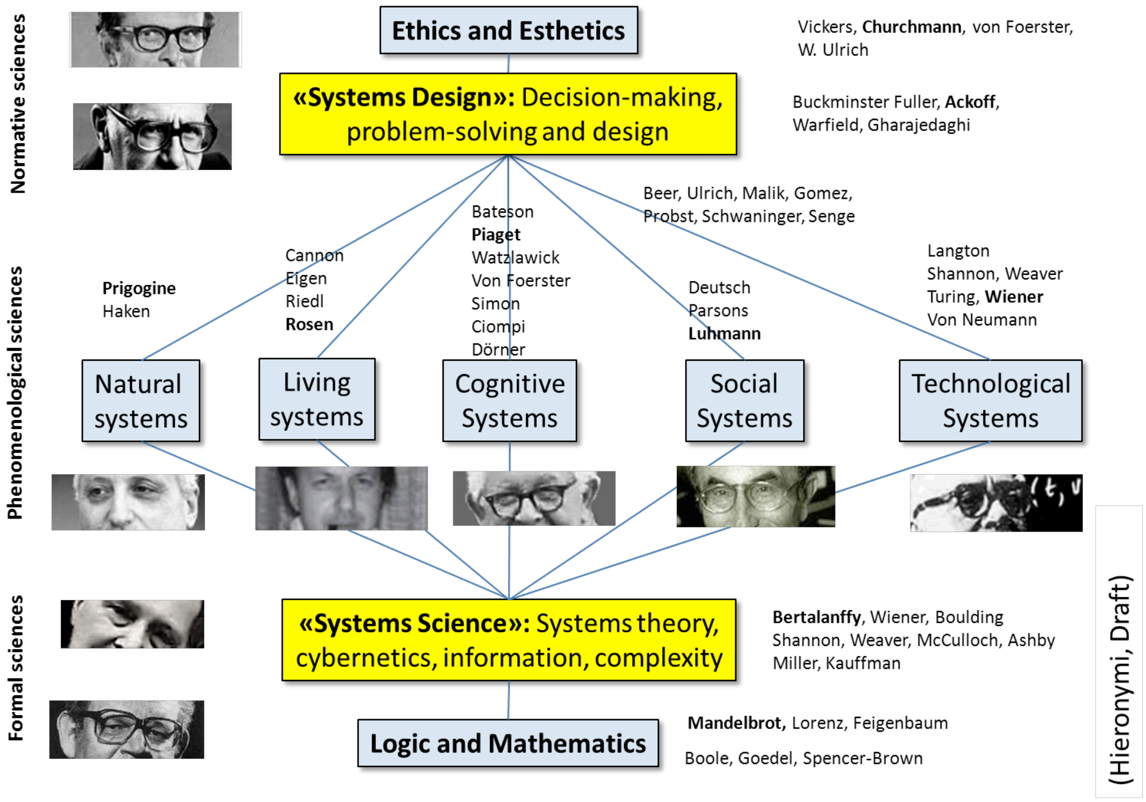


**Figure 6: Description of systems thinkers and their allocation in the field of the sciences (Hieronymi, Draft).**

Systems science is not a closed but rather an open field. In the graphical representation above about fifty people considered to be systems thinkers are represented. The representation is only for illustrative purposes and not comprehensive. Some of these individuals worked mainly in the field of systems theory itself. **Bertalanffy** and others developed the foundations of general systems theory. There are also many specialists of traditional schools of thought who broadened those fields using systemic methods of thinking. **Mandelbrot** developed fractal mathematics. **Prigogine** did research on self-organization in the field of chemistry. **Rosen** did work on system-oriented theoretical biology. **Piaget** developed systemic approaches to mental development. **Luhmann** developed a systemic theory of society. **Wiener** invented the field of cybernetics and laid foundations for computer technology. **Ackoff** developed system-oriented problem-solving methodologies for management science. **Churchman** emphasized philosophical and ethical aspects of systems methodology.

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[12] More on systems thinkers: Ramage & Shipp (2009). This volume presents a biographical history of the field of systems thinking.

## 9. ASKING SYSTEMIC QUESTIONS BASED ON THE DEVELOPED FRAMEWORK

**(See Appendix: A General Systems Inquiry)**
How can we make elements of systems theory more accessible? How can we reduce the often-mentioned gap between theory and practice?

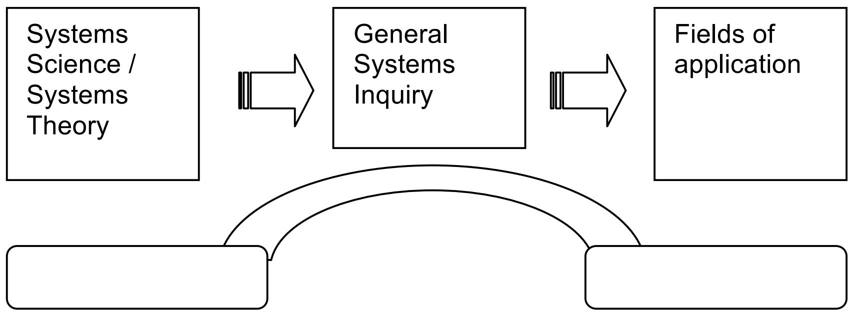


**Figure 7: One way of transferring theoretical systems knowledge to applied fields is through a systematic sequence of theory based questions that in a further step can be applied to specific fields of application.**

The list of questions in the APPENDIX (A General Systems Inquiry) of this paper is based directly on the presented theoretical framework and models on the previous pages. It addresses those practitioners among the readers who want to apply systems knowledge to specific systems and to problems of special interest. This might involve, for example, coaches, managers or project leaders who wish to better understand a system and improve it. Possible topics that can be explored with the help of this instrument include: Planning a start-up-company; analyzing problems of a project-team; finding ideas for sustainable health interventions; discussing viewpoints for desirable city development.
The goal of the series of questions is to provide a balanced and broad range of systems perspectives. In the sense of a general systems approach, the questions have been kept on an abstract level without focusing on a particular case. It is in the hands of professionals skilled both in systems theory and counseling that this instrument will show best results. Depending on the individual case, the consultant or coach will select the order and wording of questions, specifying them in respect to the specific fields and goals. This will facilitate interdisciplinary dialogue among specialists, decision makers and other stakeholders in finding appropriate answers.

## 10. CONCLUSION

The sub-disciplines of systems science can be viewed as different perspectives on a set of general system principles and thus form a unity through their interlinked diversity. Systems science and its interdisciplinary concepts and language provide a bridge between science and the humanities, between descriptive research and normative practice, thus making a contribution to the unity of knowledge.

This project has been conceived in the sense of providing maps for depicting the field in a new way. The maps and tables presented here are products of work in progress in the full knowledge that other maps might be more appropriate from other perspectives or pragmatics. They are not exhaustive but aim to highlight connections and give a conceptual overview. It should further interdisciplinary dialogue and be a starting point for improved versions. Such an integrative presentation can motivate discussions regarding self-description within systems science and about similarities and differences of the sub-disciplines. Given the breadth of the topics and themes, it is obvious that sufficient depth has yet to be achieved. I welcome replies and corrections, and would be happy to participate in further development and cooperative projects.

*An earlier and shorter version of this paper was presented at the EMCSR, Vienna, 10-13 April 2012.*

## APPENDIX

## A GENERAL SYSTEMS INQUIRY
(v 1.2a)

Asking systemic questions based on the developed framework

*(Introduction to this approach: see Chapter 9)*

**Questions about the categories of systems involved (5 categories)**
The following set of questions will help to identify what kinds of system categories (see Table 1) are relevant in the context of the addressed system or problem.

- **Physical systems perspective:** What influence do natural resources (such as clean water) and environmental conditions (such as storms) have on the system in question?
- **Biological systems perspective:** What biological processes, plants or animals have an influence on the favorable development of the system in question? Are there any possible health risks or threats?
- **Cognitive systems perspective:** What significance do the individual ideas, thoughts and emotions of the participating persons have for the success or failure of the system or project? What habituation or learning processes could occur?
- **Social systems perspective:** What social components and dynamics should be considered? What economic and political aspects are of significance?
- **Technological systems perspective:** What technical requirements should be considered? What technical risks must be taken into consideration?

Interconnect and balance the perspectives:
- Which systems perspective has a higher direct relevance? Which one can be easily neglected while possibly having an indirect, hidden or delayed effect on the system in question?
- How much can the systems mentioned here be treated independently? Or do they influence each another?
- What kind of scientific disciplines are relevant to understanding the broad range of systems involved and their interaction?
- To what degree do the disciplines or representatives share their knowledge and values? What are the differences and possible problems in realizing a fruitful interdisciplinary dialogue?

**Questions about the relevant dimensions of knowledge (5 dimensions)**
The following set of questions describes five different perspectives of knowledge dimensions (see Table 3) to investigate a system.

**Value-oriented perspective: Ethics, esthetics, visions, goals (What is required? Why?)**

- What do we want to achieve with this system (project)? What are the overall objectives, values and success criteria? What ethical and judgmental aspects are affected when tracing the boundaries of the system and subsystems? What kinds of value systems do the different stakeholders have?

**Design Perspective: Systems design, problem-solving (How do we get there?)**

- What general design and problem-solving strategies are best for reaching the desired goals? What kind of practices and habits are familiar to the stakeholders?

**Phenomenological perspective (What is there? What happens?)**

- How can we gain a clear, correct and holistic overview of all relevant aspects, parts, contexts, levels, interactions and dynamics of the systems in focus? (See also above: "Categories of systems"). How do our views and terms differ? Are we aware of the differences?

**Systems science perspective (How does it work?)**

- How can we describe by means of a simplified model how the system works? How can we simulate its dynamic behavior and its interaction with the environment?

**Logical and mathematical perspective (How can we measure/predict?)**

- How can the system or relevant aspects of it be measured? How can its behavior be calculated and predicted over time?

Interconnect and balance the perspectives:

- Can these perspectives be treated independently or are they connected with each other?
- Do the stakeholders or participants agree on relevant values, best strategies, correct descriptions of reality, appropriate modeling tools and quantitative methods?
- Which of these perspectives are of higher or lower relevance in dealing with the system in question?
- What helps stakeholders decide whether hard numbers and calculations or soft values and visions should be given higher priority in a specific decision?

### Questions based on a set of system principles

The following questions address ten suggested system principles (see Chapter 4). These principles, functions or capabilities appear to be important in order that a (living) system can survive, adapt and flourish. If one of these aspects is diminished or missing, it might need to be supported by or substituted with other means. Principles 0 and 10 address the same theme of "system boundary and unity," but on a different level of observation. A core research topic of the author of this paper is analyzing and developing these principles further in theory and practice. The list starts out with more basic principles and concludes with more complex ones.

### Principle 0: Limit, Unit, System

What elements and connections lead to the observed system structure and limitation? To what extent do the existing elements and connections agree with the required arrangement for complete functioning and for the aims of the system? (Completeness):

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**Principle 1: Energy, Activity**
In which events can the relevant activities and processes for the functioning of the system be recognized? How good is the relationship between the required energy and the rendered achievement? (Efficiency)

**Principle 2: Calculation, Control, Regulation**
On the basis of what rules and process steps does the system control its activities? How well do the implementations agree with the specifications? (Correctness)

**Principle 3: Perception, Signals, Differentiation**
What inner or outer signals in the system lead to process-relevant information and classifications? How high is the usual rate of agreement between the identified object and the real situation? (Recognition Rate)

**Principle 4: Robustness, Continuity, Resources, Stocks**
How can the stability and continuity of critical system resources and processes be recognized? How well and how frequently does the usual stock agree with the required stocks? (Availability)

**Principle 5: Identity, History, Changes, Development Process**
What existing characteristic conditions and behaviors influence the identity and development of the system in indefinite and novel situations? How often do the steps taken lead to an improved mastery of future situations? (Learning Ability)

**Principle 6: Adaptation, Flow Equilibrium**
How can self-regulated adaptations, corrections and state transitions be recognized? How reliably and efficiently do regulations introduced after deviations lead to (renewed) obtainment of the preferred inner conditions? (Aptness)

**Principle 7: Exploration, Creativity**
In what ways is the system capable of creating new links, ideas, strategies and behaviors? How well do the new solutions agree with present and future challenges? (Solution Quality)

**Principle 8: Goal Orientation, Planning**
By means of what mechanisms does the system create short-term and long-term priorities, strategies and plans for the future? How well do the prognoses and intentions agree with the behaviors and successes reached? (Forecast Quality)

**Principle 9: Communication, Interaction**
By what means does the system communicate and interact with other systems? How well and how frequently do the intended contents and effects between sender and receiver mutually agree with each other? (Compatibility)

**Principle 10: Relationships, Social Systems, Networks**

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How can longer-term relationships and cooperation of a system with other systems be recognized? To what extent do the effects aimed for by means of the alliance agree with the expectations of the parties involved? (Function Fulfillment)

Interconnect and balance the perspectives:

- Which principles are most relevant for the short-term and long-term survival and prosperity of the system?
- What systems principles are best/worst developed at present?
- For which principles are errors and failures most likely to appear?
- What kinds of principles enhance each another, and which are competing with each other in the system in question?

Using the perspectives and questions described above, we can arrive at a quite comprehensive description of a system, problem or plan. Very different perspectives find access into the discussion and can be connected with each other.

The content and structure of this list of systems questions was elaborated by Andreas Hieronymi. Feedback for theoretical and practical improvement is most welcome. For further information please contact the author.

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