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## Understanding Systems Science: A Visual and Integrative Approach

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## ■ *Research Paper*

# Understanding Systems Science: A Visual and Integrative Approach

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Systems thinking is considered a much-needed competence to deal better with an increasingly interlinked and complex world. The many streams within systems science have diversified perspectives, theories and methods, but have also complicated the field as a whole. This makes it difficult to understand and master the field. Short introductions to fundamental questions of systems science are rare. This paper is divided into three parts and aims to do the following: (1) to provide a broad overview of the structure and purpose of systems science; (2) to present a set of key systems principles and relate them to theoretical streams; and (3) to describe aspects of systems-oriented methodologies within a general process cycle. Integrative visualizations have been included to highlight the relationships between concepts, perspectives and systems thinkers. Several new attempts have been made to define and organize system concepts and streams in order to provide greater overall coherence and easier understanding. © 2013 The Author. *Systems Research and Behavioral Science* published by John Wiley & Sons, Ltd.

**Keywords** systems science; systems theory; complexity; philosophy of science; systems thinking

## INTRODUCTION: BACKGROUND AND PROBLEM

What skills are needed for the 21st century that have been neglected in the past? It has become increasingly clear that the problems and challenges we face are highly interlinked, complex and

multidisciplinary. A comparative study (Wiek *et al.*, 2011) came to the conclusion that one of five key competencies for a sustainable future is 'systems thinking competence'. Peter Senge, one of the key promoters of organizational learning and systems thinking in management (1990), argues that three core capabilities are necessary: We need to increase 'collaboration across boundaries', 'see systems' as a part of larger systems and learn to 'create a desired future' (Senge *et al.*, 2010, p. 44). These three challenges are closely related to the three foundational aspects of systems science explored in this paper.

The goal of this paper is to make key perspectives and concepts of systems thinking and systems

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science more understandable to researchers and to persons involved practically in fields such as education, consulting or management. To achieve this goal in the limited space of this paper, emphasis will be on visual maps that help us to integrate systemic knowledge from diverse streams and to highlight relations. More detailed descriptions of the concepts mentioned can be obtained in the cited references. Troncale (1985, p. 30) states 'There is a need to make general systems theory more user-friendly'. Among other solutions, he recommends overcoming obstacles by use of graphic techniques. There exist several definitions of systems science.

Systems science is the ordered arrangement of knowledge acquired from the study of systems in the observable world, together with the application of this knowledge to the design of man-made systems. (M'Pherson, 1974, p. 229)

[Systems science] does not aim to find the one true representation for a given type of systems (e.g. physical, chemical or biological systems), but to formulate general principles about how different representations of different systems can be constructed so as to be effective in problem-solving. (Heylighen, 1990, p. 423)

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. (Klir, 2001, p. 5)

Systems science can be defined as the scientific exploration and theory of systems in the various sciences, such as biology, sociology, economics, etc., while general system theory concerns the principles that apply to all. (Strijbos, 2010, p. 454)

Klir (2001, p. 5) states that systems science, like any other science, needs to distinguish among three components: 'A domain of inquiry', 'a body of knowledge regarding the domain' and 'a methodology'. These three components will also be addressed in the three parts of this paper. Figure 1 gives an overview on how this paper is structured, starting with transdisciplinarity (part

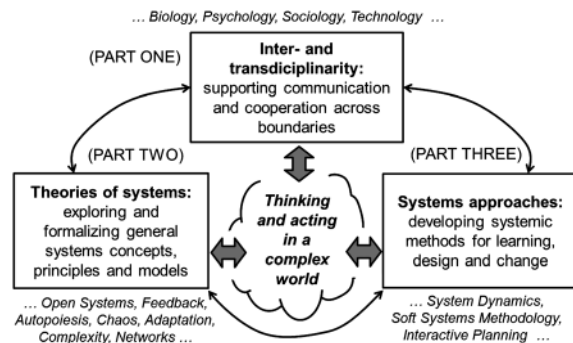


Figure 1 Three faces of systems science and respective parts of this paper

one), followed by theories of systems (part two) and systems approaches (part three).

The history of systems science has its beginnings in the years around 1950 (Hammond, 2003) with the work of founding fathers such as Bertalanffy, Wiener, Rapoport, Boulding and Miller. The emergence of systems thinking is closely linked with the endeavour to overcome previous boundaries within academia and practice (*interdisciplinarity and transdisciplinarity*). Researchers in fields such as biology, psychology, sociology and technology collaborated on urgent real-life problems and on investigating general principles and theories on how systems function in general (*theories of systems*). Terms were newly created or specified, such as feedback, autopoiesis, chaos and complexity. These concepts received increasing interest in applied fields so that many methods and methodologies emerged that incorporated aspects of systems theory in order to improve practice (*systems approaches*). The goal is to better understand how different sorts of systems work and how to deal with complex situations and reduce unwanted side effects.

Over 40 years ago, Ackoff (1971, p. 661) was insisting on more coherence on the theoretical side of the systems field:

Despite the importance of systems concepts and the attention that they have received and are receiving, we do not yet have a unified or integrated set (i.e., a system) of such concepts. [...] This state is aggravated by the fact that the literature of systems research is widely dispersed and is therefore difficult to track.

[...] Contributions are not as interactive and additive as they might be.

A similar critique is made by Warfield (2003, p. 507). He considers systems science to be 'very broad in its scope and far reaching in its implications for practitioners', but in his view, systems science is still in 'a formative stage'.

There is not a corresponding understanding concerning the content of systems science. On the contrary, there are dozens of small systems societies that speak to widely differing points of view as to what constitutes systems science for their members. (Warfield, 2003, p. 508)

Warfield insists that every science—including systems science—needs a 'central purpose', 'a corpus [...] that consists of foundations and theory' and a 'methodology as a defined process' (2003, p. 508). Troncale (2006) makes a comparable point: 'The overall field of systems science is still in formation' (p. 554), and 'there is still insufficient integration of the many different strains of systems theory and systems tools' (p. 560).

The hypothesis of this paper is that steps towards a better integration of the systems field can be made by exploring and visualizing systems science as a system itself. What function does systems science have within its larger system? What are the functions of the subsystems of systems science? And how do the parts of systems science relate to each other and create a bigger whole?

## PART ONE: SYSTEMS SCIENCE AND TRANSDISCIPLINARITY

Many theoretical and practical problems cannot be understood and solved by a single discipline alone. Interdisciplinarity involves work between fields and learning about each other, whereas transdisciplinarity involves work in which new shared concepts are needed, and work that bridges theoretical and practical issues. Systems science grew out of the need to communicate across disciplinary boundaries. 'We must stop acting as though nature were organized into

disciplines in the same way that universities are' (Ackoff, 1960, p. 6).

The so called systems approach is often portrayed as a counter-current to the increasing fractionation of science into highly specialized branches resulting in a breakdown of communication between the specialists. (Rapoport, 1986, preface)

Today, systems science and the field of interdisciplinarity and transdisciplinarity still share many similar goals and partly overlap. One way to think about the structure and boundaries of disciplines is by means of visual science maps, including the simple ones in this paper, or more sophisticated ones such as those Börner (2010) is elaborating by use of immense amounts of data.

Through maps of science, we can begin to see all that we know as landscape – viewed as if from above or from a great distance. Science maps provide guidance for navigating, understanding and communicating the dynamic and changing structure of science and technology. (Börner, 2010, p. ix)

Other maps describing the landscape of the sciences and the emerging field of systems science are provided in Müller (2011), for example.

## Systems Science within the Science System

What are the role, purpose and place of systems science in the landscape of the sciences? How would a librarian classify the books in this field? Is systems science closer to computer science, or management, or theoretical biology, or is it more similar to mathematics? The following map (Figure 2) provides an overview regarding the position that systems science could be assigned within science as a whole. Five horizontal system categories are combined with five vertical knowledge dimensions. The result is a visual map of the sciences with two axes. M'Pherson (1974, p. 223, p. 229) and Max-Neef (2005) use similar classifications to distinguish systems and disciplines.

Figure 2 presents a map with five major science fields on the horizontal line, which revolve around the following concepts: *physical system*, *living*

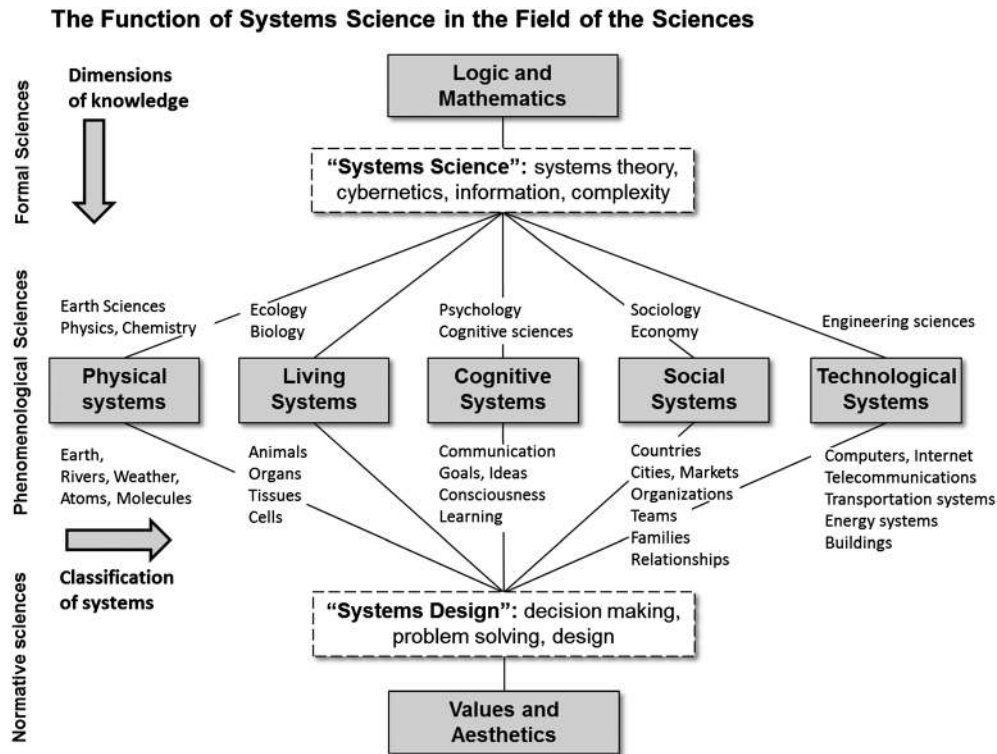


Figure 2 Map of science—with a special focus on systems science and systems design

system, cognitive system, social system and technological system. The map is extended by further knowledge fields on a vertical line: 'Logic and mathematics' are mentioned in the direction of 'formal' sciences because they are the most abstract; 'values and aesthetics' are mentioned in the 'normative' direction because they involve reflection and judgments of action. This diagram includes two further fields: systems science and systems design. *Systems science* is located on the map as a formal science between mathematics and the reality-based sciences. Boulding (1956, p. 197) states that 'General Systems Theory [...] lies somewhere between the highly generalized constructions of pure mathematics and the specific theories of the specialized disciplines'. *Systems design* refers to the heterogeneous field of general methods and practices relevant for all applied fields. Banathy (1996, p. 34) states that 'In design, we focus on finding solutions and creating things and systems of value that do not yet exist'.

Seen in this way, systems science and systems design provide a bridge between natural science and the humanities, as well as between descriptive research and normative practice, thus making a contribution in terms of inter- and transdisciplinarity.

### Mapping Systems Thinkers

In the following, the structure of Figure 2 is used to provide a short overview of a variety of systems thinkers (Figure 3). A special feature of the systems movement is the fact that its important exponents come from very different science fields. Many of the systems thinkers presented here are discussed in more detail in Ramage and Shipp (2009). Other visual representations of the systems field are given by Ison *et al.* (1997), Castellani and Hafferty (2009) and Sayama (2012).

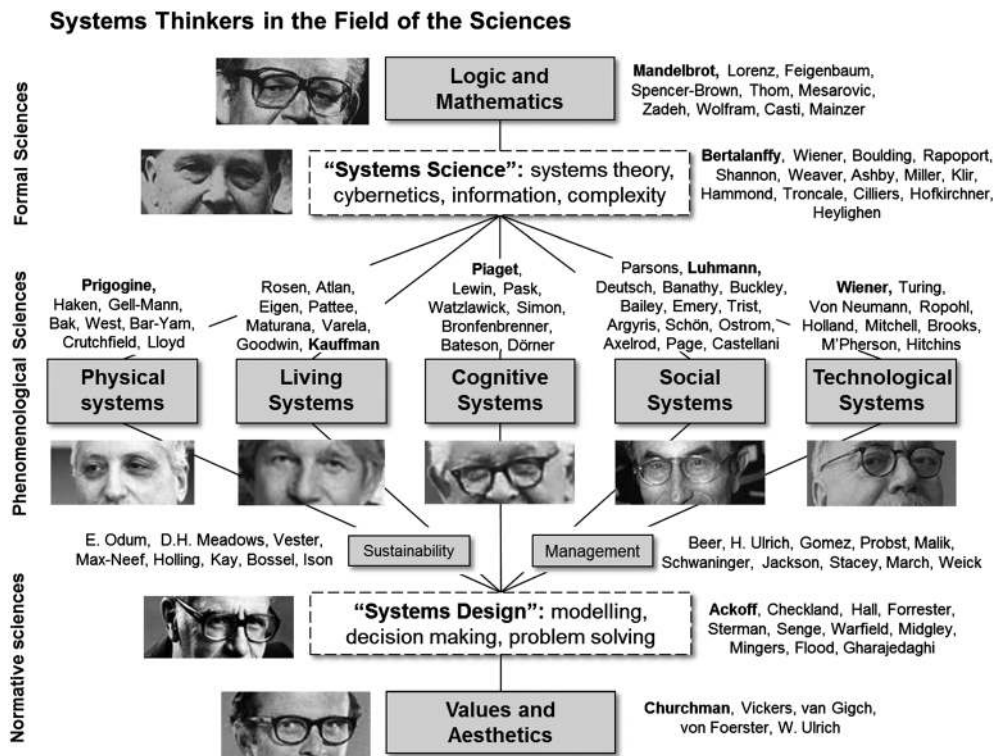


Figure 3 Overview of systems thinkers and their position in the field of the sciences

The graphical representation in Figure 3 includes over 100 people considered to be systems thinkers. They are organized according to key contributions to the field, although most of these systems thinkers could be assigned to multiple places. The list is by no means exhaustive. The names of those pictured are given in bold. The purpose of the map is to stimulate interest in and discussion on systems thinkers. This map is based on the author's familiarity with the systems thinkers presented in it, as well as additional feedback obtained at two systems-oriented conferences. Most systems thinkers have developed their own unique understanding of systems definitions and concepts. Often, terms and concepts of systems theories are optimized for a certain field, such as for managers, social scientists or engineers. Part two, on the other hand, attempts to create a multidisciplinary view of systems.

PART TWO: THEORIES OF SYSTEMS

There is no generally agreed on 'systems theory'. The focus in this section is on different notions of defining systems and a variety of systems principles.

The task of a general theory of systems would include that of defining a system, of formulating a taxonomy of systems, of singling out properties that various systems have in common, and of explaining how this approach can help us to a better understanding of our world. (Rapoport, 1986, p. 1)

'A scientific field can arise only on the base of a system of concepts. Systems science is not an exception' (Ackoff, 1971, p. 671). Researchers in several fast-growing scientific fields realize that the theoretical foundations of their own fields

are strongly related to or even directly based on systems science – such as in sustainable development (Weinstein and Turner, 2012), public health (Luke and Stamatakis, 2012), service systems (Maglio, Kieliszewski and Spohrer, 2010) and systems engineering (Pyster and Olwell, 2013). This situation demands from the subdisciplines within systems science increased collaboration to provide a coherent body of knowledge, including definitions, concepts, classifications and related general methods to deal with complex situations. Additional educational strategies and tools are needed to facilitate teaching and learning systems science and to creatively apply its principles in a wide variety of settings.

## Definitions of a System

What is a 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, such as physics, chemistry, mathematics, logic, cybernetics, economics, linguistics, biology, psychology, as well as in the majority of engineering branches. Klir (1965, p. 29)

Although the concept of a system is now very widespread, we still have a situation in which multiple definitions co-exist. Rather than an error, this reflects the multidimensionality of the concept, ranging from simple to complex notions (Figure 4). Some researchers understand systems as the simplest form possible: ‘A system is a set of objects together with relationships

between the objects and between their attributes’ Hall and Fagen (1956, p. 18). Others use the word ‘system’ to connote a relatively complex adaptive system, which has many interrelated subsystems and is once again a part of a larger system: ‘CAS [Complex adaptive systems] are systems that have a large number of components, often called agents, that interact and adapt or learn’ Holland (2006, p. 1).

Figure 4 indicates that, depending on the perspective, different properties are connoted with the word ‘system’. The next section takes a closer look at this problem and proposes a hierarchical approach to differentiating between several systems principles and types.

## Principles of Systems

The founders of the systems movement stressed the importance of general systems principles and concepts.

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. von Bertalanffy (1956)

‘Proponents of general system theory purport to seek integrating principles sufficiently general to apply to many different contexts: physical,

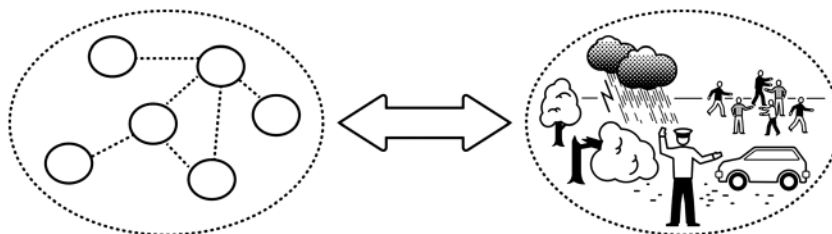


Figure 4 Two extremes of defining a ‘system’. Left: A ‘system’ in the sense of simple elements with relations. Right: A ‘system’ in the sense of an adaptive agent interacting within a dynamic environment, that itself is a system of systems

biological, psychological, and social' Rapoport (1986, preface). What general principles/features can be defined that differentiate or unify certain instances of systems in a logical and coherent way? This is one of the most central questions in systems science, and there has been no consensus. One of the earliest hierarchies of system types was proposed by Boulding (1956). Miller (1978) proposed in his 'living systems theory' a collection of 20 general system components that can be found on many levels of systems. Other suggested systems principles and types can be found in Ackoff (1971), Mingers (1995), Martinelli (2001), Meadows (2008) and Lin *et al.* (2012). The following list of principles (Figure 5) has been newly elaborated by the author and is the result of extensive research on the literature in multiple fields of knowledge.

These principles comprise a core element of the author's intended future research. Certain similar principles/characteristics of systems can be found in theoretical biology (e.g. Koshland, 2002; Elitzur, 2005), in developmental psychology (e.g. Piaget, 1971; Fischer, 1980; Commons *et al.*, 1998) as well as in artificial intelligence and robotics (Braitenberg, 1984; Pfeifer and Scheier, 2001; Russell and Norvig, 2003). What kind of features does a system need in order that the parts can build an integrated whole, the system is able to adapt to changing environments and the system itself can finally be a functional part of a bigger (group) system and contribute to it? The proposed principles (Figure 5) are described in the following text 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. The

chosen key terms appear in quotation marks. Criteria for their selection were that they are short, easily understandable and can be used in several areas of application. Other synonyms might be more appropriate depending on the context and scientific perspective. More important than the terms themselves are the described functions behind the terms. This process of concept building and classification is not yet finished, it is still at an early stage, open to discussion and further improvement.

- 'Boundary': A system exists as a unity by means of the relations between its elements and the boundary that differentiates the system from its environment. In that basic sense, the system can still be a 'static system' (connected elements within a boundary).
- 'Energy': If energy flows through a system that enables movement, it becomes an 'active system' (energy flow, motion).
- 'Computation': If a system is capable of processing and computing relevant data and directing its actions based on rules, a system becomes a 'rule-based system' (data processor, rules, computation). In this general sense, every living cell is in the process of computing data—not just computers.
- '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' (sensors, perception, monitoring, feedback).
- 'Robustness': If a system can store energy and make use of stored energy, this can enable the system to reliably maintain critical processes and structures—and endure and survive even

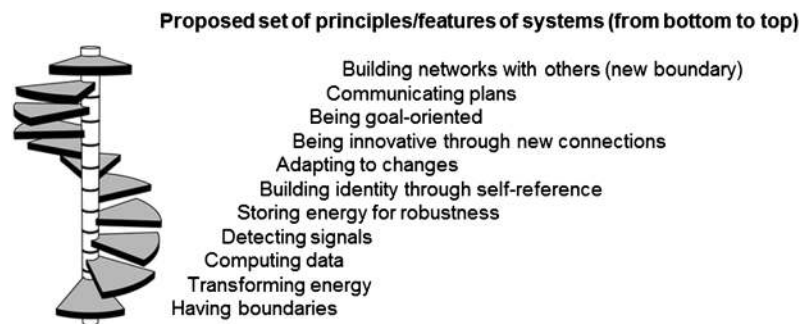


Figure 5 List of proposed general principles of systems. The metaphor of a circular staircase expresses the idea of hierarchical systems principles moving from bottom to top to reach the next systems level



without a continuous flow of energy from outside. It becomes a 'robust system' (energy storage, redundancy, robustness, stability).

- 'Identity': If a system can build up memory and refer to some of its own present and past states and conditions, it can thereby create representations and a sort of identity. The system might now exhibit increasingly path-dependent, nonlinear, unpredictable and chaotic behaviour. This can be described as a 'self-referential system' (identity, individuality, memory).
- 'Adaptation': If a system attempts to maintain or 'bounce back' to inner conditions that are favoured, it assumes a form of homeostasis and becomes an 'adaptive system' (internal homeostasis, adaptation, resilience).
- 'Innovation': If a system can actively search for and create new internal connections and connect information in new ways, it can become an explorative learning system. In this sense, it is enabled for innovation and evolution. This can be described as an 'evolutionary system' (creativity, innovation, thriving).
- 'Organization': If a system is able to control given goals and establish future goals that organize and integrate its behaviour and can include multiple priorities in a ranking order, it becomes a 'goal-oriented system' (goals, organization, priorities).
- 'Communication': If a system can communicate internal conditions, knowledge and goals to other systems and prompt them to take action, it becomes a 'communicative system' (messages, interaction, communication).
- 'Next-level boundary': On the basis of communication, a system can build longer-lasting connections to other systems so that a new communication-based unit and boundary emerges. This leads to a 'social system' (relationships, networks, alliances). We have thus reached a higher and emergent boundary level.

This closes the circle of the described set of principles, and the evolving process can be repeated on the next level: A group of 'agents' can build up their shared capability to collectively define boundaries, take action, establish rules, monitor inner and outer processes, store resources, develop an identity, adapt, innovate, organize itself and, as a group, communicate and collaborate with other

groups or even be a functional part of a broader organization. These aspects have parallels in many areas, for instance, about how to define characteristics of organizations (Katz and Kahn, 1978) and how communities collectively manage common goods (Ostrom, 1990).

On the basis of the principles described here, a type of a system can be classified in terms of the most prominent or highest principle reached. A 'type' refers to 'all the agents in a population that have some characteristic in common' Axelrod and Cohen (2000). The aforementioned list makes it possible to distinguish between 'passive systems' (such as a table) and 'active systems' (such as a steam engine), for example. A company might behave on the market like an adaptive system (react to changes to maintain identity) or an innovative system (intensive search for new solutions). Similarly, Morgan (1986) used system types to classify organizations. The aforementioned list of hierarchical systems principles and types needs further ground work to demonstrate its relevance in different areas of application.

### Subdisciplines of Systems Science

If systems science is not a homogenous field, what subdisciplines belong to it and how do they relate to core functions and principles of systems? It should be possible to analyze how influential various traditions of systems science have been in establishing or clarifying some key systemic principles. There have been many historical overviews on the development of systems science (e.g. François, 1999; Hammond, 2003; Schwaninger, 2009; Merali and Allen, 2011). Here, we will focus on the following traditions: thermodynamics, open systems theory, information theory, cybernetics, theory of autopoiesis, chaos theory, complexity theory, (multi-)agent modelling and network science.

These traditions can be summarized as follows.

- *Classical thermodynamics* treats closed systems in an energetic equilibrium. Nevertheless, it is not designed to treat systems in non-equilibrium (for an overview, refer to, e.g. Atkins, 2010).
- *Open systems theory* describes the necessity of living systems being energetically open to the environment (von Bertalanffy, 1950).

- *Information theory* treats the storage, compression and transmission of data (Shannon and Weaver, 1949).
- *Cybernetics* describes feedback processes for regulating systems (Wiener, 1948; Ashby, 1956).
- *The theory of autopoiesis* clarifies how living systems reproduce and maintain themselves continually (Maturana and Varela, 1980).
- *Chaos theory* indicates the reasons for instability and nonlinear change processes (Mandelbrot, 1983; Gleick, 1987).
- *Complexity theory* describes processes of self-organization, adaptation and innovation (Kauffman, 1993; Holland, 1995; Kauffman, 1995).
- *(Multi-)agent modelling and the concept of autonomous agents* make it possible to formulate and simulate processes of systems (agents) that act in a goal-oriented manner, e.g. humans and robots (Axelrod, 1997).
- *Network science*, finally, is concerned with the interaction of numerous actors, their process patterns and dynamic social structures (Watts and Strogatz, 1998; Barabasi, 2003; Watts, 2004).

The similarities and differences among these streams can be better understood if we take a closer

look at what kind of systems principles/concepts they mainly focus on and how the whole field developed. The systems principles proposed earlier in this section are used now as a classification scheme to organize subdisciplines of systems science.

Figure 6 provides a combination of the aforementioned subdisciplines and the set of proposed systems principles. Systems principles (vertical axis) are presented from bottom to top in a suggested hierarchical order from low to high degrees of complexity. Subdisciplines of systems science (horizontal axis) are presented from left to right in a rough chronological order. The timeline begins with thermodynamics and then encompasses around 60 years of systems science. The ‘correlations stars’ introduced here are based on initial suggestions of the author and discussions with system thinkers at two conferences. Both the principles and the subdisciplines are broad in their scope, and there exist many different views on how to define them, which can lead to different results. If the concepts and subdisciplines are arranged as in Figure 6 then the distribution of the ‘correlation stars’ (\*) indicate a visual trend line moving from the lower left to the upper right corner. This leads to the following two hypotheses.

Comparison chart		Subdisciplines								
		Thermodynamics ~1850	Open Systems Theory ~1940	Information Theory ~1945	Cybernetics ~1950	Theory of Autopoiesis ~1975	Chaos Theory ~1980	Complexity Theory ~1985	(Multi-) Agent Modeling ~1995	Network Science ~2000
Systems principles (concepts)	Network, Group, Emergent boundary							*	*	***
	Communication, Interaction, Cooperation			*	*				***	***
	Organization, Goal-orientation, Planning				*			*	***	*
	Innovation, Creativity, Evolution						*	***	*	*
	Adaptation, Adjustment, Resilience		**		**	*	**	***	*	*
	Self-reference, Identity, Individuality					**	***	***	*	*
	Robustness, Stability, Maintainance		**		*	***	*			
	Perception, Sensors, Feedback			**	***	*			*	*
	Computation, Rules, Data processing			***	**		*	*	*	*
	Energy flow, Movement, Activity	***	**	*	*	*	*	*		
System boundary, Interlinked elements, Set	*	***				*	*		*	

Figure 6 Comparison chart displaying systems principles and subdisciplines of systems science. One to three stars (\*) indicate a suggested correlation between the theoretical field and the proposed systems principle.

*Hypothesis 1:* The development of systems science, with its various subdisciplines, followed a process in the sense of paradigm shifts and scientific revolutions.

*Hypothesis 2:* The development of systems science has approached and clarified principles and concepts with increasing levels of complexity.

The prevailing subdiscipline describes a particular viewpoint and aspect of reality. With time, however, it reaches its limits in explaining or predicting the anomalies of behaviour in the system in question. In the sense of Thomas Kuhn's paradigm shift (1970), small scientific revolutions have occurred in this respect: changes in perspectives, changes in the mental models and methods of the researchers. Often, these shifts are also supported by the use of more sophisticated and more efficient calculation methods and computer resources. The interpretation of the visual results in Figure 6 provides a possible way of better understanding some controversies, debates or separation lines between subdisciplines. Systems science needs integrating forces to overcome the historical borders in order to progress and fulfil its function within science, education and practice.

The aforementioned hierarchy of systems principles and types is in close agreement with the argument of Troncale (2006, p. 317): 'We concluded then that it was more reasonable to expect a hierarchy of partial theories than to expect one overarching general theory.' A similar way of relating concepts with subdisciplines of systems science is proposed by Dent and Umpleby (1998), who discuss eight 'underlying assumptions' in the light of six 'systems science traditions'.

### PART THREE: SYSTEMS APPROACHES TO CHANGE

From a scientific viewpoint, general systems principles are worthy of investigation, as science is always attempting to find the simplest and most general laws, principles and mechanisms in explaining reality. But how do insights in systemic knowledge also inform the way we design

change and intervene in systems? Over the past 60 years, many systemic methods have been developed to put systemic concepts and principles into practice. The following section takes a closer look at methods used in areas close to management, problem-solving and design. Not treated here are other systemic methods such as those developed in the fields of medicine, therapy and other applied areas.

Simple tasks do not require major thinking or planning. Classical analytical problem solving works fine for isolated problems with pre-stated goals. Systemic methods, on the other hand, are especially helpful when many different stakeholders interact in a dynamic complex setting, where there is no initial consensus on the problem definition, the expected future, or a shared vision of what to reach. Terms such as 'wicked problem' or 'mess' express how traditional problem solving has its limits.

When one enters the field of systems approaches, it becomes difficult to maintain an overview and understand similarities and differences. Reynolds and Holwell (2010, p. 9) see strengths and weaknesses in the systems movement: 'In the systems field there is no shortage of approaches; it is diverse with many concepts, methodologies, methods and techniques. [...] We may well have inadvertently created a complex clutter of systems approaches.' Detailed discussions of specific systemic methods are provided by Midgley (2000) and Jackson (2003), for example. Recent practically oriented introductions can be found in Reynolds and Holwell (2010) and Williams and Hummelbrunner (2011). Ulrich and Probst (1995) as well as Gomez and Probst (1995) offer further insights into integrated and systemic problem-solving methods.

Figure 7 shows a new way of visually interconnecting and explaining systemic methods and aspects of several methodologies. This overview is not exhaustive. The spiral in the middle of Figure 7 indicates that learning develops in cyclic steps. The four stages in the illustration have points in common with concepts derived from Kurt Lewin's idea of action research (1946), such as experiential learning (Kolb, 1983), reflective practice (Schön, 1983), appreciative inquiry (Cooperrider and Srivastva, 1987) and process

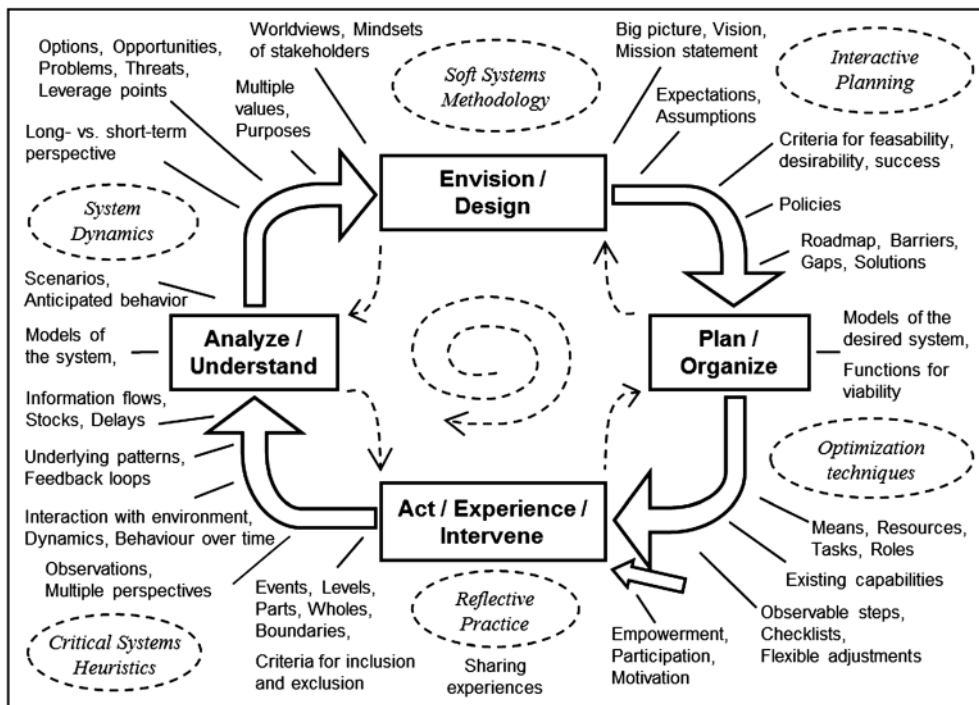


Figure 7 Proposed process cycle involving four general steps to illustrate systemic aspects and methodologies

cycles used in other areas. The stages (act, analyze, envision and plan) used for this framework are explained in the following.

- ‘Act/Experience/Intervene’: Complex situations are always unique, and therefore, direct experience of actors/observers from several perspectives and on several levels is needed.
- ‘Analyze/Understand’: In order to understand the causal relationships within complex situations, it is often necessary to look at dynamic behaviour over time, series of events, patterns of behaviour and underlying structures (e.g. feedback loops).
- ‘Envision/Design’: Complex situations often cannot be solved with predefined solutions from the past. It therefore becomes necessary to take diverse values and stakeholders into account to detect the opportunities and threats, define a shared vision, find ideas and select feasible solutions.
- ‘Plan/Organize’: To plan successfully, it is necessary to consider interdependencies on various

levels and timelines. Sustainable solutions for complex problems need to build on the existing resources and strengths while also building up new capabilities. The participation of involved actors in the planning process makes use of all existing knowledge, reduces the risk of resistance and increases the chance of a successful implementation that will be in accordance with the main vision. However, complex situations can change fast so that new direct experiences and adjustments become necessary.

When dealing with complexity, such a process normally does not end after one cycle but continues iteratively: The defined boundaries might be reduced or enlarged, and the values and expectations attached to the result might change as well.

Six specific system methodologies have been mapped onto the illustration (dotted circles in Figure 7). Each place represents one major strength of each methodology, although all of them are much broader in their coverage. The precise

placing is debatable. Although a methodology is mapped in one corner of the framework, it can nevertheless be used to go through the whole process cycle without having to make use of other methodologies. The following is a short description of these six systems methodologies.

- *Critical systems heuristics* (Ulrich, 1983) involves detailed considerations about how to draw the boundaries when considering systems. The question about what is relevant and what is less important involves values and facts and can have strong political and ethical implications.
- *System dynamics* (Forrester, 1971; Sterman, 2000) is an elaborated qualitative and quantitative method for understanding, modelling and simulating dynamic systems.
- *Soft systems methodology* (Checkland, 1981) helps to explore multiple perspectives, reach accommodations between those perspectives and define action plans that are systemically desirable and culturally feasible.
- *Interactive planning* (Ackoff, 1981) is a methodology that involves idealized design to define a far-sighted but still actionable plan.
- *Optimization techniques in the tradition of operational research* (OR; Churchman *et al.*, 1957) are a set of methods for improved decision making and efficiency.
- *Reflective practice* (Schön, 1983) emphasizes the process of continuous and deep learning. Good practice requires reflection, and good learning requires experience. In complex systems, it is nearly impossible to achieve perfect prediction and error-free plans. It thus becomes crucial to learn through direct interaction with the respective system.

Every methodology has its own strengths and weaknesses. In the past 30 years, several authors have presented integrative, multimethodological frameworks to compare and combine several systemic methodologies, such as Hall (1989), Flood and Jackson (1991) and Schwaninger (2004).

Another way of mapping systemic methodologies within a process of several steps is provided by Mingers (1997). The timescale to run through a full cycle can vary greatly. Three examples will illustrate this. A recent approach that combines several powerful methodologies within a full learning cycle is the systems-based 'evolutionary learning laboratory' (ELLab) (Bosch *et al.*, 2013). In an ELLab, 'a diverse group of participants engage in a cyclical process of thinking, planning, action and reflection for collective learning towards a common good' (Bosch *et al.*, 2013, p. 118). It has been successfully applied in fields such as sustainable development or the design and improvement of educational programs. The timescale of an ELLab might be weeks, months or years. The methodology as described in Figure 7 builds on existing theories and experience. It has been applied by the author in the fields of coaching, team development and facilitating change. In this case, the timescale to run with participants through the full cycle can range from a couple of hours to days or weeks, depending on the addressed issues. It is not the intention to claim in Figure 7 that systemic thinking always needs to explicitly involve all mentioned aspects or be purely sequential; many systemic aspects can be found in parallel processes of thinking in action by professionals in complex situations that may just last minutes or seconds. Dancers coordinate their movements with the movement of the whole group in real time; a saxophonist coordinates his or her solo with the jazz band and the clapping of the audience; a firefighter coordinates his or her actions with colleagues within a collapsing building. All these professionals embrace all four quadrants mentioned here (act, understand, envision and plan) parallel to each other and in real time: acting, reflecting on interactions, seeing emerging possibilities, seeing the situation through the eyes of others, balancing one's own values and those of others, balancing short-term and long-term outcomes, finding feasible solutions and empowering others. Such complex multifaceted behaviour has similarities with what Hämäläinen and Saarinen (2004) call 'systems intelligent behavior'.

## CONCLUSION

When we are confronted with the many perspectives, concepts, principles and methods in the systems field, there is a danger of not seeing the forest for the trees. Visual maps help us to integrate knowledge and establish relations between the concepts. This paper has attempted to bring together a wide variety of perspectives and concepts to underpin three aspects of systems science: supporting interdisciplinarity and transdisciplinarity, exploring and formalizing systems concepts and developing systemic methods for learning and change.

Figure 8 is related to Figure 1 and shows that a desirable cooperation between different components of the systems field leads to a mutual strengthening. Similar descriptions of components and interactions are given in M'Pherson (1974) as well as Flood and Carson (1993). Isolated development of any one of these components will probably have limitations. A steady information flow between these components is necessary to strengthen the co-evolution of theories, methods and applications. Further investigations could clarify which of these proposed linkages are strong, which are weak and how they could be improved.

The figures and ideas presented in this paper are works in progress. Other representations might be appropriate from other perspectives. The paper offers initial arguments to support the following statements:

1. Researchers and practitioners in interdisciplinary and transdisciplinary fields can make use of systems concepts and methods to facilitate practice. Systems science and systems design provide a bridge between science and the humanities, as well as between descriptive research and normative practice. This can improve mutual understanding and enhance communication.
2. The subdisciplines of systems science can be viewed as different perspectives on a set of general systems principles, thus forming a unity through their interlinked diversity. Systems science seems to be an appropriate name and framework in bringing these

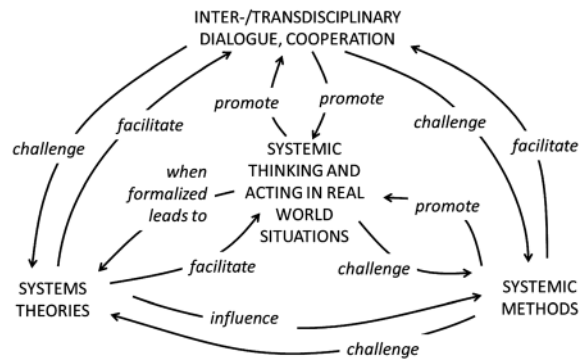


Figure 8 Mutual influence of four components in the systems field (adapted from Flood and Carson, 1993, p. 4)

- forces together. Work towards coherent theories of systems lead to synergetic effects and strengthen the function of systems science within the landscape of the sciences.
3. Systemic methods show many varieties in detail and points of focus, they provide rich potential for dealing with complexity and change. Stronger connections between different schools of thought facilitate the use of methodologies in educational and applied settings.

These statements support the idea of an integrated pluralism that appreciates both diversity and unity. Many real-life situations require holistic solutions that involve working across disciplines, principles and methods. At present, some of the older separation lines are disappearing, and the systems field is gaining momentum as a whole.

Figure 9 is related to a quote by Peter Senge. The quote agrees very well with the aforementioned statements and describes the importance of making systems knowledge known to a wider audience:

A real change is grounded in new ways of thinking and perceiving. [...] With nature and not machines as their inspiration, today's innovators are showing how to create a different future by learning how to see the larger system of which they are a part and to foster collaboration across every imaginable boundary. These core capabilities—seeing systems, collaborating

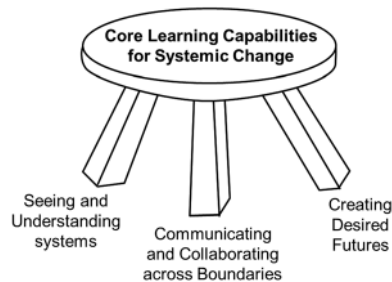


Figure 9 Three capabilities for systemic change. (Adapted from Senge et al., 2010, p. 45)

across boundaries and creating versus problem solving—form the underpinnings, and ultimately the tool and methods, for this shift in thinking. Senge et al. (2010, p. 10–11)

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Given the breadth of the topics addressed, it is clear that there is much room for delving more deeply into the subject matter. The website [www.understandingsystems.net](http://www.understandingsystems.net) provides links to some of the papers, concepts and systems thinkers mentioned in this paper. Feedback and suggestions for improvement and applications are most welcome.

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