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CHAPTER 31

Systems thinking

SYTSE STRIJBOS

Systems thinking is one form that interdisciplinarity has adopted since the middle of the twentieth century. It is a catchall term for different postwar developments in a variety of fields, such as cybernetics, information theory, game and decision theory, automaton theory, systems engineering, and operations research. These developments concur, however, inasmuch as, in one way or another, they relate to a basic reorientation in scientific thinking attempting to overcome ever-increasing specialization, and trying to make a shift from reductionist to holistic thinking, while acknowledging the unity of reality and the interconnections between its different parts and aspects.

There have been a number of attempts to define interdisciplinarity and identify its different types. Of particular interest in the present case is Margaret Boden (1999), who distinguishes six forms ranging from weak to strong: encyclopedic, contextualizing, sharing, cooperative, generalizing, and integrative types of interdisciplinarity. Encyclopedic interdisciplinarity requires no exchange or sharing between any disciplines involved, whereas integrative interdisciplinarity demands rigorous interaction. The latter is thus, according to Boden, the most genuine kind of interdisciplinarity as 'an enterprise in which some of the concepts and insights of one discipline contribute to the problems and theories of another—preferably in both directions'. Artificial intelligence (AI), a field in which Boden has a scholarly reputation, is in her view an excellent example of integrated interdisciplinarity. Each of the main types of AI, traditional or symbolic AI, connectionism, and 'nouvelle AI', has borrowed concepts from other disciplines such as philosophy, logic, psychology, and neurophysiology.

How does systems thinking fit into this typology? Boden labels the proposal for a 'general systems theory' that was launched by Ludwig von Bertalanffy and others in the middle of the twentieth century and Norbert Wiener's closely related idea of cybernetics as examples of 'generalizing interdisciplinarity', defined as 'an enterprise in which a single theoretical perspective is applied to a wide range of previously distinct disciplines'. Also the more recent developments in the area of complexity studies can be regarded as an example of this type. Boden (1999, p. 20) correctly notes that it is no accident that these examples are all heavily mathematical: 'The abstractness of mathematics enables it to be applied, in principle, to all other disciplines'.

Boden nevertheless fails to note some of the ways systems thinking has developed. In his later work von Bertalanffy for instance has distinguished between general system theory *in a broader sense* and *in a narrower sense*. Although von Bertalanffy's own theoretical work focuses on the latter, he stresses in his *General system theory: foundations, developments, applications* (1968), a collection of articles published over a period of more then 20 years, that he had both in mind from the outset. His concern is not just with a certain theory but the breakthrough of a new paradigm in science. Different postwar developments, such as cybernetics, information theory, network theory, game theory, systems engineering and related fields culminated in the birth of the systems movement when von Bertalanffy joined with Boulding, Rapoport, and Gerard to establish in 1954 the Society for General Systems Research, an association that still exists under the name of the International Society for the Systems Sciences. Stimulated by this new scientific association, a dynamic, broad-based field has developed and a multiplicity of approaches and trends has arisen.

With the increasing expansion of systems thinking, von Bertalanffy felt the need to distinguish different domains. Following his distinctions, the wide range of studies in the systems field—general system theory in a broader sense—can be divided into three realms or basic types. The first is *systems science*, which 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. The second realm is *systems approach in technology and management* that concerns problems arising in modern technology and society. While philosophy is present in the areas of systems science and systems technology, *systems philosophy* can be distinguished in the systems field as a third domain in its own right. In the view of leading systems thinkers such as von Bertalanffy the introduction of 'system' as a key concept entails not only a total reorientation in science and technology, but also in philosophical thought.

To explore the implications of systems thinking for interdisciplinarity it is appropriate to consider each of the domains more in detail. In what follows some main lines will be sketched, rather than pursuing an encyclopedic overview of the developments in each domain. A broad and rather up-to-date documentation of the systems field can be found in *Systems thinking* (2002), a four-volume collection edited by Gerald Midgley that includes more than 70 classic and contemporary texts, including some critical evaluating studies.

31.1 Systems science

The well-known stock phrase that 'a whole is more than the sum of its parts' stems from a tradition in Greek philosophy, older than the conceptual use of the term 'system', that speaks of wholes that are composed of parts (Harte 2002). This whole–part relationship attracted renewed scientific interest in wholeness and the whole arising in the early twentieth century. Exploring the genealogy of contemporary systems thinking, reference has been made to Jan C. Smuts (1870–1950), a South African statesman and philosopher who is often depicted as a white supremacist supporting a racially segregated society (cf. Shula Marks 2000). In his book *Holism and evolution* (1926) he created the concept and word 'holism' (derived from the Greek *ὅλος*, *holos*, meaning whole, and entirety), expressing the idea that all the properties of a given system (biological, chemical, social, economic, mental, linguistic, etc.) cannot be determined or explained by its component parts alone. Instead, the system as a whole determines in an important way how the parts behave. It has also been claimed by Mattessich (1978) and others that the Russian philosopher and scientist Alexander A. Bogdanov (1873–1928) worked out the first version of a general systems conception in his book *Tektologiya: vseobschaya organizatsionnaya nauka* [*The universal science of organization: essays in tektology*] (1922). Both Smuts and Bogdanov had thus anticipated systems ideas at the beginning of the twentieth century. However, the conceptual use of 'system' as a technical term in science and technology arose some decades later and has become ubiquitous since the 1950s.

The philosopher–biologist Ludwig von Bertalanffy (1901–72) became one of the leading figures in the rise of systems thinking by coining the concept of a 'system', or more precisely the concept of an 'open system', as a key concept in the quest for a unified science incorporating all the disciplines, each corresponding to a certain segment of the empirical world. Just like Smuts, von Bertalanffy was also inspired by the debate in the biological sciences in the first decades of the twentieth century. Struggling with the controversy between two competing views, the dominant mechanistic-causal approach and vitalist-teleological conception, he did not take one or other side but proposed what he called an 'organismic' view. At issue was the possibility of an explanation for the phenomena of life that would have the status of an exact science, not through a *reduction* of biology to physics but through the *expansion* of classical physics into a broader, exact natural science. Von Bertalanffy considered this idea of expansion of scientific concepts as a key that opens the door to very far-reaching scientific developments. The extension of the domain of exact science from physics to biology must be carried further. Organismic biology, he argued, which focuses on the study of the organism as an open system (in contrast to the study of closed systems in classical physics) becomes in its turn a borderline case of the so-called 'general system theory'. The concept of the 'open system' was for him the truly 'general system' concept enabling the integration of all the sciences into a general system theory.

Like von Bertalanffy, the economist Kenneth E. Boulding (1910–95) was one of the early pioneers and founders of the systems movement. Being aware of the increasing difficulty of profitable exchange among the disciplines the more science breaks into subgroups, Boulding started pursuing the unity of sciences as an economist within the social sciences. Early in his scientific career he became convinced that all the social sciences were fundamentally studying the same thing, which is the social system. In his book *The image: knowledge in life and society* (1956a) Boulding introduces the 'image' concept, apparently inspired by Shannon and Weaver's concept of information, serving as a basis for the desired integration of the social sciences. And in a classic article 'General systems theory: the skeleton of science', published in the same year (Boulding 1956b), he pointed out the next step towards a general systems theory, incorporating all the sciences. Boulding sketched two possible approaches in the interdisciplinary quest for a general systems theory. A first approach is to identify general phenomena which are found in many disciplines, such as the phenomenon of growth. A second, more systematic, approach is to arrange the empirical fields in a certain hierarchic order, a hierarchy of systems in which each higher systems level has a higher degree of complexity. This issue of hierarchy has subsequently been widely discussed in the systems literature, e.g. by Herbert Simon in an often reprinted paper about 'The architecture of complexity: hierarchic systems' originally published in 1962.

Looking back over a period of more than 40 years Peter Checkland (1999, p. 49) made the observation that the original interdisciplinary project of the founders cannot be declared a success. A meta-level kind of approach leading to a greater unification of the sciences as envisaged has not occurred. However, one can admit that systems ideas and concepts have been incorporated in many disciplines. And sometimes new systems concepts and insights born in one discipline have contributed to the problems and theories of another. An impressive example of such an exchange between disciplines—or integrative interdisciplinarity, speaking in Boden's typology—is the work of the social scientist Niklas Luhmann (1927–98).

Aiming for a unified social theory, a general theory of social systems, Luhmann argues in his *Social systems* (1995) that two subsequent paradigm changes have taken place on the level of general systems theory, showing a shift from an ontological to a more functionalistic systems concept, i.e. from thinking in terms of wholes as unchangeable substances to systems that maintains themselves in a dynamic exchange with their environment. The first move in this direction was due to von Bertalanffy in the mid 1950s. By proposing the concept of the 'open system' a transformation of thinking took place in which the traditional difference between *whole and part* was replaced by *system and environment*. Like any paradigm change, Luhmann notes, this implies a conceptual broadening. What has been conceived of previously as the difference between whole and part, the old paradigm, was reformulated by this new schema as system differentiation and thereby built into the new paradigm. Systems differentiation can be understood as the repetition within systems of the difference between system and environment.

The second paradigm change and move towards a more radical functionalistic way of thinking is due to developments in systems science leading to a theory of *self-referential systems*. Initial efforts in the 1960s, in which Heinz von Foerster (1911–2002) played a leading role, employed the concept of self-organization. Self-organization is the phenomenon of self-reference with regard to the structure of a system, that is to say that structural changes are produced by the system itself. Self-reference in a more encompassing way, however, also include the elements composing a system. For this purpose the biologists Humberto Maturana and Francisco Varela (1946–2001) created the term *autopoiesis* (self-creation). Autopoiesis thus means that a system has the ability to reproduce itself at the level of its own elements.

According to Luhmann, a theory of self-referential systems as the most recent general system theory opened up important avenues for a general theory of social systems. This broadening of the general system concept from 'open system' to 'self-referential system' enabled Luhmann to avoid criticisms of the views of Talcot Parsons, his great predecessor in sociology, whose social systems theory was the dominant paradigm in sociology during the 1950s and 1960s. While very influential for a few decades, Parsons' systems theory was also widely criticized as a legitimization of the status quo. It was charged that Parsons' systems approach was inherently conservative in its focus on the maintenance of social order and in emphasizing consensus at the expense of acknowledging social change and conflict. Profiting from newer developments in systems science, Luhmann succeeded in the 1980s to propose a new social systems theory, turning around Parsons' structural-functionalism into a functional-structural systems approach.

Mapping interdisciplinary research

Katy Börner and Kevin W. Boyack

This box reviews existing approaches to visualizing interdisciplinary research from a science mapping perspective (Börner *et al*. 2003). Although visualization is often the way in which the results of analysis are communicated, visualization (or, in our case, mapping) is not analysis. The purpose of mapping is simply to visually display the results of analysis to enhance communication of those results. Maps often play the role of templates upon which the results of previous analyses are overlaid.

Conceptualizing science for mapping

Measurement of the degrees of interdisciplinarity and generation of maps on which those measurements can be displayed can only be done within a recognized framework or conceptualization. Although such conceptualizations can be very detailed, containing (1) units of analysis, (2) their interactions, (3) basic mechanisms of growth and change, and (4) system boundaries (Börner and Scharnhorst 2009), the conceptualization can be highly simplified for the specification of interdisciplinarity. Although the units for analyzing and mapping interdisciplinarity could be authors, journals, disciplines, or even countries, the key facet is to be able to define their disciplinary inputs and outputs. Thus, a map showing the results of an analysis of interdisciplinarity would need to have units and show the relationships between those units. In addition, it might include a time dimension to see changes in structure and/or dynamics. Last, but not least, it would need to describe the boundaries of the analysis (e.g. neuroscience by itself; neuroscience in the context of all of science; or all of science). By way of example, we discuss co-author collaboration, journal citation, and paper citation flow analyses and maps here.

Collaboration maps

Co-authorship networks can be generated for authors from a specific institution, country, or a specific field of science. They are often visualized in a node-link diagram (authors as nodes; co-authorships as lines linking authors) that places linked authors in close spatial proximity and unconnected authors further apart, while minimizing the number of link crossings. If the author nodes are colored by discipline, authors with interdisciplinary co-authorships are easily identified in the author map.

Journal network maps

The measure of *betweenness centrality* has recently been promoted as a measure of journal interdisciplinarity, and to good effect. Given that betweenness is a network measure, based on the links that would be shown in a network map if it were drawn, such maps are a natural way to display the results of these analyses. For example, Leydesdorff and Schank (2008) show maps of the local citation networks for several different journals, each showing the key 'central' position of a particular journal. In one case, for the journal *Nanotechnology*, they animate a sequence of annual maps generated from citation statistics. The visual maps correlate well with the betweenness measure for *Nanotechnology*; a dramatic rise in betweenness correlates with *Nanotechnology* taking the central linking position in the field away from the journal *Science* in the early 2000s.

(*cont.*)

Mapping interdisciplinary research (cont.)

Knowledge flow maps

While collaboration studies focus on the assembly and impact of (inter)disciplinary teams, knowledge flow studies try to answer questions related to the diffusion of expertise and/or knowledge over time, geospatial space, and topic space.

Knowledge diffusion is often measured using citation relations. The fact that paper A cited paper B is taken as an indication that knowledge diffused from B to A, although it is difficult to quantify just how much and what type of information was truly transferred. Papers can be aggregated to journals resulting in journal citation networks. Journals can be aggregated into disciplines or scientific fields. *Historiographs* are visualizations of small, localized, paper citation networks over time. Other network visualizations help to understand the 'super highways' of information diffusion as well as knowledge hubs and authorities.

Typically, the topical composition of nodes, as well as the type and strength of their interlinkages, changes over time. The figure illustrates this effect by showing the topical composition and changes in citation flows for 14 major subdisciplines of chemistry, biology, biochemistry, and bioengineering (see Boyack *et al*. 2009 for details).

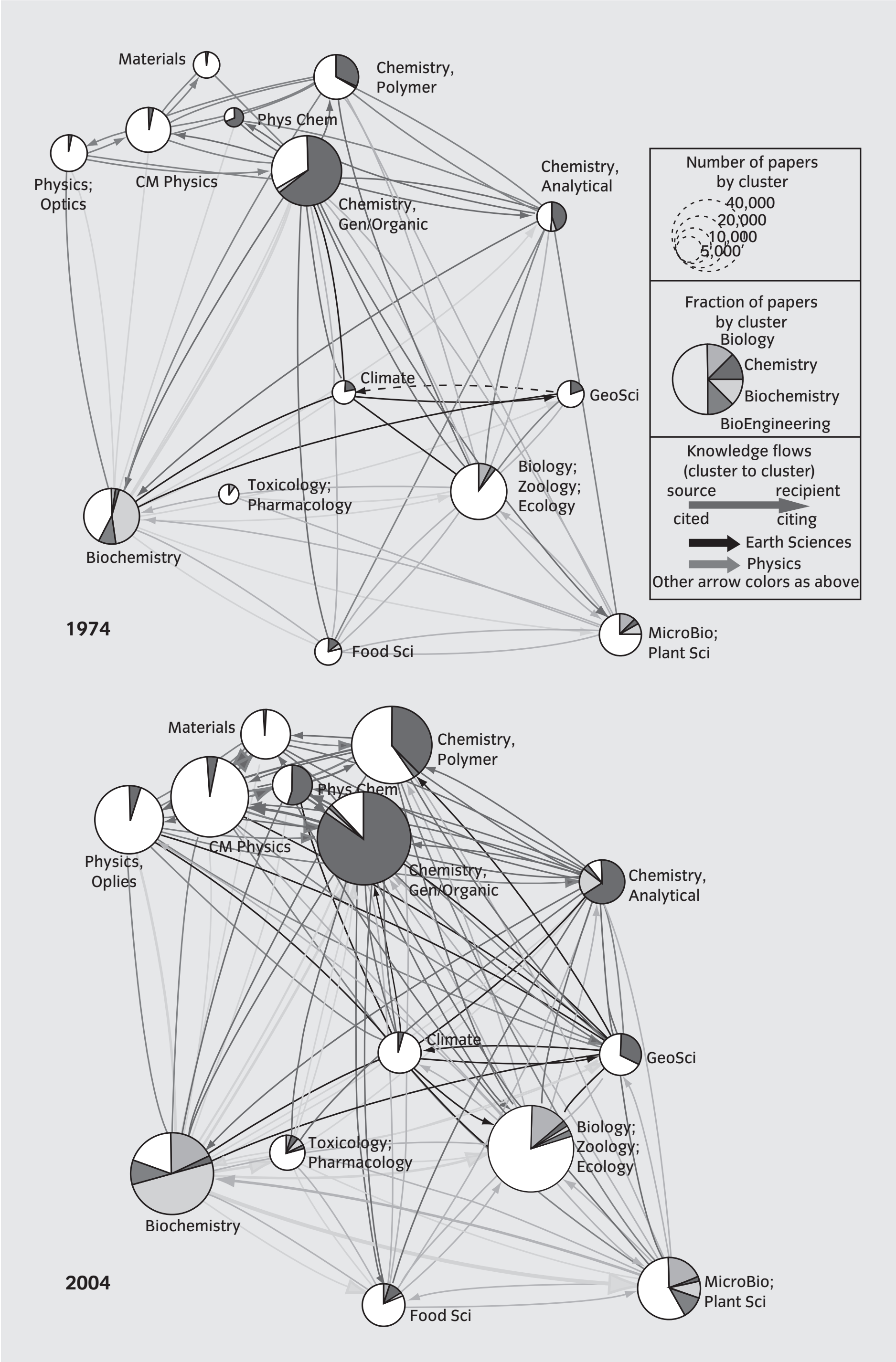
Each node in the figure represents a cluster of journals, where the disciplinary composition of journals is denoted by pie charts and where the disciplinary assignments for each journal are based on their Thomson Reuters categories. Seven categories are used in the figure (those denoted by the six colors, and 'Other'). The areas of the pie charts scale with the number of papers, thus accurately representing the relative sizes of the different subdisciplines. Knowledge flows among these 14 subdisciplines in terms of number of direct citations are represented by arrows. Arrows denote the flow of information from the cited subdiscipline to the citing subdiscipline. Arrows inherit the color of the knowledge source, and are proportional in thickness to the square root of the number of citations. Changes in topical composition and knowledge flows can be animated over time. Maps at 5-year intervals along with specific observations drawn from the maps are available in the original work.

Outlook

Current research on mapping science includes the creation of standards for sharing scientific and technical data, including means to connect different types of data organized by different taxonomies and classifications across fields and languages. For example, it is desirable to interlink publications with patents and funding as well as with the impact on education and training, and economic activity.

Clarification on what actually constitutes 'interdisciplinarity' for the purpose of measurement and mapping is also needed. The pie charts in the figure are more aptly described as multidisciplinarity than as interdisciplinarity. Such definitions may also be discipline- or even team-specific. Better understanding of the real-life types, mechanisms, and amounts of knowledge generation and transfer and how they could be approximated using data from bibliographic databases is needed.

The communication of results, via network drawing or other map types, for example, has to meet the needs of the intended user group and their tasks. Today, it is not clear what metaphors work best to depict something as abstract as science—charts, networks, geospatial maps. How many dimensions does it take to render science?—do one-dimensional time lines suffice, are topic maps best, which map types are best to communicate interdisciplinarity, an so on.



Map of 14 major subdisciplines, fractions of papers by field for each subdiscipline, and knowledge flows between subdisciplines for 1974 (top) and 2004 (bottom).

(*cont.*)

Mapping interdisciplinary research (cont.)

These are just few of the many questions asked by the Mapping Science exhibit (<http://scimaps.org/>). Maps featured in this exhibit provide first answers for specific user groups such as science policy makers, researchers, or commercial decision makers. Ultimately, the inner workings and impact of interdisciplinary research should be communicated and understood by scholars and the general public alike.

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31.2 Systems approach in technology and management

Parallel to the rise of the interdisciplinary movement in the sciences, the need has also increasingly been felt for integration and general frameworks in the fields of technology and management. While science concerns the pursuit of knowledge for the solution of theoretical problems, technology and management aim at shaping or altering reality in addressing real-world problems. However, these problems have become so complex that traditional ways and means are no longer sufficient and approaches of a generalist and interdisciplinary nature have become necessary. Nowadays the realm of systems approaches in technology and management comprises a broad spectrum of issues ranging from environmental modeling and world modeling in the early 1970s, to studies in business strategy and management of organizations, medical practice and family therapy, human development and poverty issues, to the quickly developing field of industrial ecology since the 1990s.

The roots of this domain in systems thinking are quite complex and go back to various developments that happened during or shortly after World War II. One important aspect is that engineering has been led to think not in terms of single machines and separate technical artifacts but in terms of larger 'systems': the engineering of the telephone network, for example, rather than the telephone instrument or the switching equipment. Traditionally, engineers are used to tackling practical problems by analyzing their parts and finding a solution for the different parts. As the name *systems engineering* suggests, the idea took hold that the traditional approach of engineering separate components needed to be extended to approach systems made up out of many components that are interacting. Engineers speak about electric systems, power systems, transportation systems, computer systems, etc. The initial use of the term 'systems engineering' with roughly its present meaning probably began in the early 1940s at the Bell Telephone Laboratories (Schlager 1956). A leading pioneer was the electrical engineer Arthur D. Hall (1925–2006) who worked for many years at Bell Labs and in 1962 published the first significant book on systems engineering entitled *A methodology for systems engineering*.

A development closely related to systems engineering is *operations research* or 'operational research' as it is known in the United Kingdom. Briefly discussing the difference between both fields, Hall (1962, p. 18) noted that operations research is usually concerned with the operation and the optimization of an existing system, including both humans and machines, while in contrast systems engineering focuses on the planning and design of new systems to better perform existing operations or to implement new ones never performed before. In the aftermath of the war C. West Churchman (1914–2004) and Russell L. Ackoff, who were inspired by American pragmatism and aimed to apply this philosophy to societal issues, became leading scholars in North America in the incipient fields of operations research and systems thinking. Together with E. L. Arnoff they published one of the field's first textbooks *Introduction to operations research* (Churchman *et al.* 1957), which became internationally recognized. The book emphasized an interdisciplinary team-based approach, characterizing operations research as 'the application of scientific methods, techniques and tools to problems involving the operations of a system so as to provide those in control of the system with the optimum solution to the problem'.

Simultaneously with the development of systems engineering and operations research, an approach emerged in the 1950s that was known as *systems analysis*; at that time it was closely associated with the RAND Corporation (RAND being an acronym for 'Research ANd Development'), a not-for-profit organization in the advice-giving business established in 1948. From the 1960s, RAND-style systems analysis began to find broader industrial and governmental uses, leading to a 1972 initiative by 12 nations to set up a non-governmental interdisciplinary research institute in Austria—the International Institute for Applied Systems Analysis (IIASA). Systems analysis was defined by Quade (1973, p. 121) as 'analysis to suggest a course of action by systematically examining the costs, effectiveness and risks of alternative policies and strategies—and designing additional ones if those examined are found wanting'. A case described by Miser and Quade (1985) is a policy analysis clarifying the issues for a governmental decision in the Netherlands after the North Sea flood of 1953 about the protection of the Oosterschelde estuary from flooding.

Acknowledging the differences that are present in their background and concerning particular features of systems engineering, systems analysis, and operations research, these systems approaches show important commonalities. They all rely heavily on the methods of the natural and technical sciences. Consequently they aspire to describe phenomena by mathematical-statistical models, while holding the assumption that an optimal solution exists for a problem situation which may be uncovered in this way. Another member of this family of approaches is *systems dynamics* which gained a certain reputation in the

1970s in the work of Forrester (1971) and Meadows (1972) on world modeling for the Club of Rome.

Examining the origins and nature of systems engineering and systems analysis, Checkland (1978, p. 107) concluded that a single view underlies these approaches: 'there is a desired state, S(1), and a present state S(0), and alternative ways of getting from S(0) to S(1). "Problem solving," according to this view, consists of defining S(1) and S(0) and selecting the best means of reducing the difference between them'. This constitutes what Checkland called *'hard' systems thinking*, defined as any kind of systems thinking which adopts the means–end schema. Although this model may be useful for engineering-type problems, it has a very limited applicability. Hard systems thinking demands that objectives can be clearly defined; however, an important aspect of many 'soft' problem situations is that the involved parties are likely to see the problem situation differently and define objectives accordingly. Checkland was thus faced with the challenge of rethinking the failing concept of a systems approach rooted in the engineering tradition. This led to his conceptualization of a soft systems approach in the 1970s that admits the human dimension, dealing with multiple perceptions of reality, values, and interests of the people involved (Checkland and Haynes 1994).

The later work of Churchman and Ackoff in North America is similar to the scientific program started in the 1970s by Peter B. Checkland and his colleagues at Lancaster University in the UK. Dissatisfied or even disillusioned with the course of operations research, Ackoff (1973, p. 670) argued that mainstream operations research as it had developed since 1950 was only useful in dealing with problem areas that can be decomposed into problems that are independent of each other. However, major societal problems such as discrimination, inequality within and between nations, increasing criminality, and so on, must be attacked holistically, with a comprehensive systems approach. Ackoff's dispute with the operations research community culminated in two papers (Ackoff 1979a,b) in which he called for a new paradigm breaking away from the ever-increasing 'mathematization' of operations research and for a return to true interdisciplinarity, involving in the research of all those affected by it.

In their plea for a systems approach Ackoff and Churchman not only triggered debate in the operations research community about the nature and characteristics of the field but also delivered a fresh input to the debate in the systems movement on interdisciplinarity. In 1963 Ackoff published an article in the Yearbook of the Society for General Systems Research in which he argued for a new vision of an integrating systems science and the difference between the conception of general systems theory. According to Ackoff the conception of a general system theory endeavors to achieve integration using the results that are available in the mono-disciplines, that is to say it attempts a unity *afterwards*. However, in his view 'the integral' precedes the disciplinary splitting of a problem into disjoint chunks—'Therefore, posing the problem of unifying science by interrelating disciplinary output either in the forms of facts or concepts (i.e. logical positivism), or laws or theories (i.e. general system theory), is to try to lock the barn door after the horse has gone' (Ackoff 1963, p. 120).

Ackoff's idea that integration has to take place a priori, i.e. in the phase of knowledge production, implies that he put emphasis on science as an activity and the scientific method employed in that activity. Integral knowledge requires an integration of the disciplines involved within an interdisciplinary framework. The integration must come during, not after, the performance of the research. In his conception of systems science, systems research is on sounder ground than von Bertalanffy's general systems theory because it takes systems as it finds them, in all their multidisciplinary glory. For the realization of interdisciplinary research Ackoff formulates three important conditions. First, it is necessary to unify the variables and concepts of the different disciplines to a common denominator. This enables the construction of interdisciplinary systems models. Second, for a healthy development of systems research an appropriate methodology is required. There is a need, for example, to develop scientific methods to evaluate and compare the performance of systems such as cars, planes, production systems, or health care systems. Third, the realization of programs of interdisciplinary 'systems research' involves special educational requirements.

31.3 Systems philosophy

The worlds of science, technology, and philosophy do not exist in isolation from each other. Because philosophy raises questions that are fundamental for science and technology one could argue that philosophy is by nature an interdisciplinary endeavor. For the sake of clarity it is therefore useful to distinguish some of the various meanings in which the term systems philosophy can be used, each standing for different themes and a different role of philosophy in the systems field.

First, systems philosophy deals with the fundamental philosophical issues involved in the realm of systems science. Such a fundamental issue in biology is the question 'what is life?' or 'how do we understand the phenomena of life?'. As we discussed, von Bertalanffy advocated a so-called organismic conception—the view that the organism is a whole or system, transcending its parts when these are considered in isolation. Searching for a satisfying understanding of the Aristotelian dictum of the whole that is more than its parts, von Bertalanffy at the same time takes a stand on another fundamental problem of Greek philosophy. There is the famous statement of Heraclitus: '*panta rhei*', everything is in flux, arguing against Parmenides who taught that only the static being was real, the fixed, and that change is an illusion. In this controversy, which has persisted in one form or another across the whole of Western philosophy and science, systems science adopts the Heraclitean point of view. The model of the organism as an open system implies that life has to be understood as primarily a stream of life. Forms and structures that manifest themselves in living nature are in von Bertalanffy's view secondary, just like social structures are secondary in Luhmann's understanding of social phenomena. Systems science thus manifests a totally dynamic view of reality in which enduring structures seem to evaporate and become volatile and dynamic.

Second, systems philosophy concerns the philosophical foundations of the systems approach in technology and management. Comparing Ackoff with von Bertalanffy, one notices that they agree that society is going through an important intellectual revolution that will usher us into a new era of science and society—in Ackoff's wording, going from a Machine Age to a Systems Age. One of the important characteristics of systems science, as we have seen above, is the priority given to the dynamic and flowing character of reality. The same characteristic seems to hold for systems research when Ackoff (1981, p. 16) points out that there is a turn from analysis to synthesis, which implies a turn to a functional understanding of the thing to be explained in terms of its role or function within its containing whole or environment. The synthetic approach does not exclude analysis, but in the Systems Age synthesis has priority over analysis, and function over structure. The turn from the Machine Age to the Systems Age even implies a different understanding of reality. Characteristic of the Machine Age is the deistic view in which God is regarded as the creator of the world as a machine which runs according to fixed laws. While the Machine Age and deism personify God as the Creator God, who is independent from his handiwork, God loses this personal and independent character in the Systems Age. Like Smuts' holism, Ackoff's (1981, p. 19) systems thinking is also infused with a rationalist pantheistic view in which the world coincides with God as the largest, all-embracing whole.

In a more elaborate way this is also the case in Churchman's work. In his view, the most fundamental and serious issues of the systems approach concern the problem of improvement. If we assume that we have the capability to improve systems, then what exactly do we mean by 'improvement' in designing interventions for our social systems? Churchman (1968, p. 2) concisely describes the fundamental problem right at the start of his book *Challenge to reason* as follows: 'How can we design improvement in large systems without understanding the whole system, and if the answer is that we cannot, how is it possible to understand the whole system?'. In a line of reasoning similar to Ackoff's, Churchman points to the tradition of analysis in Western thought that presumes that parts of the whole system can be studied and improved more or less in isolation from the rest of the system. And comparable to Ackoff, Churchman also discerns two differing views of the whole system and its relationship to God. If we assume that a Supreme Being exists, Churchman (1979, p. 41, italics added) says, 'then we have the conceptual problem of describing [modelling] His relationship to the rest of reality'. And he continues: 'Two plausible hypotheses come to mind. The Augustinian hypothesis [. . .] is that *God is the designer* of the real system, as well as its decision maker. [. . .] The other hypothesis, the one chosen by Spinoza, is to say that *God* **is** the whole system: He is the most general system'.

Third, there is the aspiration to formulate a systems philosophy as a new philosophy, of which Archie Bahm, Mario Bunge, and Ervin Laszlo are the chief proponents. As a prolific author of many books Laszlo became the most influential. Building on von Bertalanffy's ideas for a new scientific world view he developed in the 1970s the framework for a systems philosophy in tune with the latest developments in science and technology, representing a total reorientation of thought which aims to overthrow and replace the dominating mechanistic worldview and its incarnation in the industrialized and commercialized society of today. The dynamic view of reality that, as we noticed, underlies von Bertalanffy's and Luhmann's theoretical ideas and concepts, is a typical feature of the systems view of the world that has been summarized by Laszlo (1972, pp. 80–1) as follows: 'Imagine a universe made up not of things in space and time, but of patterned flows extending throughout its reaches. [. . .] Some of the flows tie themselves into knots and twist into a relatively stable pattern. Now there is something there – something enduring [. . .] "Things" are emerging from the background of flows like knots tied on a fishing net'.

Laszlo's philosophical conceptions culminate in his view on the future of humankind in our globalizing world. The general thrust of the many books that he published over a period of nearly 40 years is that contemporary society is in a critical stage of development. World society can get out of the danger zone if there is a complete turnabout at the immaterial-spiritual level. In Laszlo's view there is thus not only the need to bridge the gap between the sciences, gaining an integral scientific view of the world—more important even is the integrating role of systems thinking in bridging the divide between science and religion, between science and spirituality. The interdisciplinary challenge for systems thinking is thus extended in Laszlo's view to the search for a new uniting spirituality for humankind. From his *Introduction to systems philosophy* and *The systems view of the world* originally published more then 30 years ago up to his more recent books such as *Science and the reenchantment of the cosmos* (Laszlo 2006), such a spirituality is linked to an evolutionary dynamic view of the universe, arguing that there exists an interconnecting cosmic field that conserves and conveys information, a subtle sea of fluctuating energies from which all things arise. Similar to the pantheism of Churchman and Ackoff, Laszlo also thus rejects a personal God who is separated as creator from the universe. In his systems view of the universe, God is the all-embracing cosmic consciousness, and we are part of that.

31.4 Subsequent developments

Although systems science is perpetuated in newer developments such as systems biology, chaos theory, and the study of complex systems (Santa Fe Institute, NM, United States), the original interdisciplinary program of the founders of the systems movement has largely failed in its early aspirations to create a greater unification of the sciences, setting out general laws and principles governing the behavior of any type of system. On the contrary the systems movement was more successful in creating interdisciplinary approaches for tackling practical real-world problems. Jackson (2001, p. 234) offers two reasons why systems approaches in technology and management should have proven so successful. First, practical problems are by nature interdisciplinary and do not correspond to a single mono-discipline. Second, the systems idea provides a useful antidote to reductionism and enshrines a commitment to looking at real-world problems in terms of wholes and interconnected elements. With the work of Ackoff and Churchman in North America and that of Checkland in the UK this domain has not come to a standstill. Moving from 'hard systems thinking' to 'soft systems thinking' they in principle opened the way to further debates and advances. Ideas that have inspired subsequent developments derive from social theory, philosophy, and theology. The account I shall give here is necessarily biased by the role played by myself and the programmatic research efforts in which I am involved.

In the 1980s a program entered the stage that has been called 'critical systems thinking', a program that involved many people and gained a strong basis at the University of Hull in the UK since the appointment of Michael C. Jackson in 1979 (Jackson is also the editor-in-chief of a central journal in the systems community, *Systems Research and Behavioral Science*). An important source that supplies information about the broader context of critical systems thinking is a collection of articles *Critical systems thinking* (1991) edited by two of its main proponents Robert L. Flood and Michael C. Jackson.

Inspired by the social theorist and philosopher Jürgen Habermas, critical systems thinking tried to overcome shortcomings in soft systems thinking. Similar to Checkland's critical analysis of the origins and nature of hard systems thinking in 1978, Jackson embarked upon a similar critique of the ambitions of soft systems thinking in an early article published in 1982 on the nature of soft systems thinking. He arrives at the conclusion that although soft systems thinking has attacked the technical rationality embodied in hard systems thinking, one crucial element was never targeted—it still proceeds from existing power relationships. In Jackson's own words: 'Soft systems thinking is most suitable for the kind of social engineering that ensures the continued survival, by adaptation, of existing social elites. It is not authoritarian like systems analysis or systems engineering, but it is conservative-reformist' (Jackson 1982, p. 28). In an overview article about 20 years later Jackson (2001, p. 233) pointed out how critical systems thinking gradually made progress towards realizing its goal. After it became obvious that all systems approaches have their limitations, it was critical systems thinking which supplied the bigger picture at a meta-methodological level and 'has set out how the variety of methodologies now available can be used together in a coherent manner to promote successful intervention in complex societal problem situations'.

Independently of the group at Hull University, an important contribution to the strand of critical systems thinking was made in the 1980s by Werner Ulrich from the University of Fribourg in Switzerland. As a student of Churchman, and inspired by Kant's critical philosophy and Habermas' critical social theory, Ulrich launched a program that led to the conception of 'critical systems heuristics', exposed in his main publication *Critical heuristics of social planning: a new approach to practical philosophy* (Ulrich 1994). A distinguishing feature of this dialect of critical systems thinking is its methodological core principle, known as 'boundary critique'.

The latest development is a program that emerged in the late 1990s. This program involves a variety of disciplines, ranging from engineering to philosophy, executed by an international group of cooperating scholars affiliated with universities in different countries. In view of the need for an independent organizational basis, the Centre for Philosophy, Technology and Social systems (CPTS) was established in 1996 and is linked with the philosophy faculty of the Vrije Universiteit in Amsterdam. Inspired by the legacy of philosophers from this university, Herman Dooyeweerd (1894–1977) and his student Hendrik van Riessen (1911–2000), this program attempts to break with the Western idea of an autonomous human rationality and the absolutization of a scientific view of the world as the final horizon for human understanding. It aims to break with deism and a mechanistic-technical worldview in which God and reality are separated, but also with pantheism and a dynamic worldview blurring the boundary between God and the world. Dooyeweerdian thinking, that often has provided common ground in the CPTS program, is based on a theistic worldview that distinguishes a personal God from created reality and relates God and reality in a living, continuous, and sustaining creator–creation relationship. Churchman (1987, p. 139) once formulated as the most important question for systems thinking 'Does God exist?'. Of equal importance, however, is the next question 'If God exists, how does he relate to reality?'. Both questions are also fundamental in Christian theology and were rephrased by John Calvin (1509–74) in terms of the two connected questions about our knowledge of God and that of ourselves (Calvin 2008).

With the appearance of *In search of an integrative vision for technology*, edited by Strijbos and Basden (2006), the results of the CPTS program during its first decade have been documented. There are at least three important features that distinguish the interdisciplinary scope and character of this program. In the first place, interdisciplinarity concerns the shaping of a philosophical integrative framework that depicts the relationship between 'technology' and 'society', aiming for a normative-ethical basis to guide the development of science and technology for the benefit of society. For that purpose a systems view on 'technology and society' has been conceived in which different systems levels are distinguished (Strijbos and Basden 2006). With the help of this model it is possible to connect research—in engineering, management methodology, philosophy—on a specific systems level with research on other systems levels.

Second, an important part of the research program to which a number of people have contributed deals with the second realm of systems thinking, the study of practice-oriented systems methodologies for the fields of engineering and management. While making use of key notions of Dooyeweerdian philosophy, and in a critical conversation with hard, soft, and critical systems thinking, a new strand of systems thinking has been explored, labeled 'multi-modal systems thinking' by de Raadt (1997) or 'disclosive systems thinking' by Strijbos (2000).

Third, the CPTS program involves a wide spectrum of disciplines and thus seems to fit nicely with what Boden has classified as integrated interdisciplinarity. It even takes this type of interdisciplinarity further, aiming to bridge the gap between the natural sciences and the humanities, and between theory and practice. Borrowing distinctions from Frodeman *et al.* (2001) and Frodeman and Mitcham (2007), the CPTS research can also be characterized as a 'wide' and 'deep' interdisciplinarity, a type of interdisciplinary research that aims to be 'wide' rather than 'narrow' and 'deep' rather than 'shallow.' The narrow–wide distinction refers to whether only the natural and engineering sciences are involved or whether these are integrated with the human and social sciences. The shallow–deep distinction refers to whether interdisciplinarity is limited to scientific experts or whether people are also involved who are not academic researchers, but are experts with practical experience concerning real-world problems.

31.5 Final remarks

The discussion in this chapter focuses on the ambitions of systems thinking to attain general integrative frameworks that will enable relevant communication and exchange between the disciplines. Reviewing its now more then 50-year history, one can conclude that this interdisciplinary movement has stimulated fruitful theory formation in a broad variety of fields in the natural and social sciences but has not succeeded in achieving its original far-reaching goals. Furthermore, one can conclude that integrative, interdisciplinary systems approaches in technology and management have become well-accepted and have put normative considerations and ethical issues firmly on the agenda. With respect to this there still remains much to be done. An important challenge for the future is to foster an open and critical debate between the different systems approaches about their normative sources and underlying worldview (Strijbos 1988; Eriksson 2003). Another vital element is the establishment of links with other interdisciplinary fields, such as development studies and science, technology, and society (STS) studies, which also struggle for a better understanding of the forces shaping our times and search for strategies to address the big societal problems facing us.

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