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A Period of High Trans-Disciplinarity, 1948–1958

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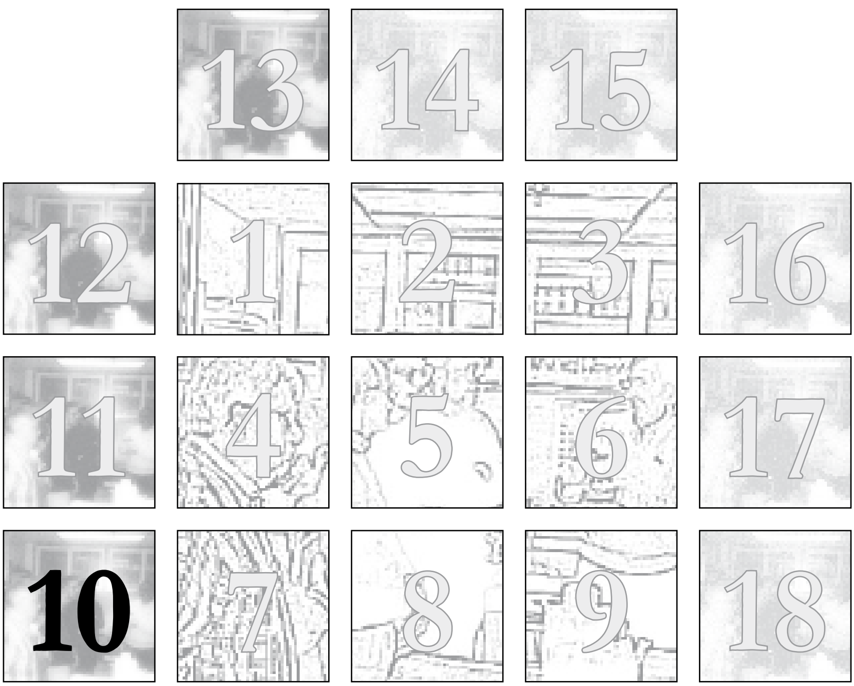


In this chapter an attempt is made to convey a fascinating and consequential episode in the history of inter- and trans-disciplinary science.[1] Here, the focus lies on radical changes and breakthroughs between 1948 and 1958, when "the paths of intellectual research in highly heterogeneous fields" (Heinz von Foerster) led to a new, sustainable trans-disciplinary reference frame. Additionally, the article suggests that the few years between 1948 and 1958 indeed served as a take-off for not just one but at least four coherent inter- and trans-disciplinary programs, which would expand, integrate, and interlink, with theoretical and conceptual cores staying more or less the same in the decades to follow. During this decade, a new connecting pattern was established between at least four adjacent nodes within the inter- and trans-disciplinary knowledge base, which has since then turned into a relatively homogeneous structure for disciplinary, inter-disciplinary and trans-disciplinary scientific languages, methods, and research designs. Furthermore, the key stages, personages, and groups, which met repeatedly in different places predominantly across the United States during these ten years and which played a crucial role in the propagation and diffusion of the new inter- and trans-disciplinary reference frame, will be discussed as well. And last, but certainly not least, this review will also pay homage to the main subject of this book – Heinz von Foerster – and provide him with the respective intellectual and technological background.

10.1 Cognitive Horizons Between 1940–1960

Nicholas Rescher (1982) notes that the scientific system undergoes cyclic changes with respect to reaching its outer limits (or completeness.) Rescher claims, albeit with a small amount of empirical evidence, that a high state of

1 According to Erich Jantsch (1972), the terms interdisciplinary or trans-disciplinary etc. should be applied as follows:

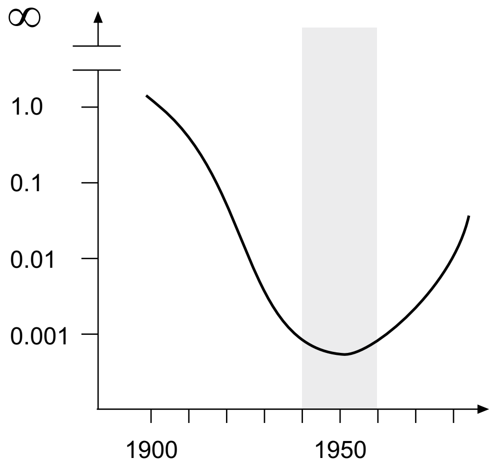
Pluri-disciplinary means a common research topic or problem area spanning several, cognitively largely varied disciplines, which can, however, still make use of their own, traditional disciplinary methods, heuristics, and theories in thematic analyses.

Inter-disciplinary comprises common languages of observation, common forms of description, measurement operations or methodologies in different disciplines, which – as a minimum requirement – have to be situated across the natural, social, or cultural sciences.

Trans-disciplinary means the application of theories, models, or patterns in different disciplinary fields, which – again, as a minimum requirement – have to be anchored in the natural, social, or cultural sciences.

scientific completeness has been perceived around 1750 and around 1900 and a very low state of scientific completeness can be recorded for the periods around 1700, 1850 and 1950. While the low status around 1850 seems to be highly debatable, a cyclical pattern of cognitive completeness seems to be highly interesting and illuminating in itself. Moreover, Diagram 1 exhibits the basic swing in the 20th century which started as a revolution in physics and was accompanied by a considerable opening in medical science and psychology and by the new science of psychoanalysis as well as by a fundamental insight into the necessary incompleteness of logical systems and mathematics.

FIGURE 1 **Open Cognitive Horizons 1900–2000**



The most important point in Diagram 1, though, lies in the cognitive status of the period between 1940 and 1960. According to Nicholas Rescher this particular phase shared a unique feature in the history of science, namely a very high value for the level of perceived ignorance and, thus, a minimal value for the ratio of

$$\Theta \text{ (level of cognitive completeness)} = \Phi \text{ (level of perceived knowledge)} / \Gamma \text{ (level of perceived ignorance)} \quad (1)$$

In other words, these twenty years are characterized by a maximum degree of open frontiers. After an already long-lasting period of scientific evolution, open cognitive horizons or frontiers can only emerge through a complete recombination in the cognitive foundations and in the scientific as well as in the technological knowledge base by discrediting old paradigms, traditional cognitive networks and the established technological infrastructure. Instead, one can observe the proliferation and diffusion of new paradigms with radically different cognitive network structures and a new technological infrastructure as well.

10.2 Changes in the Technological Infrastructure and Within the Organization of Science

There were four major areas, whose phenomenal changes during the two decades between 1940 and 1960 were highly relevant for new types of inter- and especially trans-disciplinary programs. The years following World War II, in particular, but also the scientific and technological mobilisation during the War, have had a lasting effect on the technological potentials as well as on the organisation and the contents of scientific research. In these twenty years, two initially very different technological lines were either established for the first time or substantially expanded within the societal realm.

New Information and Communication Technologies

The first major transformation took hold in the societal infrastructure long before 1940, since various new technologies from the field of information and communication had already been conceived and introduced in the 19th century[2]. With appropriate electrical codings for letters and special additional characters – first with optical, later with acoustic transformations – the so-called telegraphs[3] covered cities, countries, and, after the transatlantic cable was installed in 1868, even continents with a kind of Victorian Internet. This telegraphic revolution in the late 18th and especially in the 19th century also led to the development of the telephone – initially only as an improved version of the telegraph – and its respective networks, which now allowed the direct transport of human speech. The first two communication and information

2 In fact, upon closer examination this cluster of different technological ensembles even goes back as far as the 18th century, where during one April day in the year of 1746 a spectacular experiment was conducted outside of Paris, in which a large group of 200 monks were connected to each other with iron cables to form a line of about two kilometres in length. A small electric impulse applied to one end of this human chain caused the entire line of monks, even the one who stood two kilometres away on the other end, to be electrified and slightly shocked at practically the same time. Thus the experimental foundation was laid for the possibility to transport electricity with unprecedented speed over long distances.

3 Interestingly, it was initially going to be called "tachygraph", which means "fast writer" (Standage 1999: 10).

networks, which were a great addition to the conventional transport of material goods on streets and railroads, had thus been successfully woven into modern society. And besides the visible and tangible cables between and within societies – private households, companies, government authorities or associations were all wired together – some new invisible, forms of communication and networking also started to emerge at the beginning of the 20th century: radio waves as a transmitter of the spoken word, and later television as a transmitter of words and images. Several novel characteristics can be detected in this whole new spectrum of information and communication technologies.

One important characteristic of this cluster of new technologies was the way they successfully marginalized spatial dimensions. Written words, speech, or a sequence of images could now be sent across large distances instantaneously and with practically no loss of time, so that they were eventually no longer dependent on the speed potential of the contemporary means of transportation, above all railroads.[4] Another distinctive feature of these different information and communication technologies lies in the sequential conquest of the waveband, as the wavelength used by subsequent media continues to grow shorter and shorter.[5] Another special trait is the practically full potential for diffusion. These were the first universal network technologies that could reach virtually every single person, every household, every company, every government organisation, every scientific institution, etc. And finally, each of these new information and communication technologies exhibited an identical basic configuration, which consisted of the following building blocks: as a starting point a producer and a sender with a reservoir of certain kinds of information (text, words, images, etc.); a transmitting device, which encoded this information into a technologically suitable form (as for instance the binary notation of dots and dashes in the Morse code); a signal path, on which these encoded messages were transported over very long distances, as well as various disturbances and disruptions occurring along the way; a receiver, which decoded the received information; and finally an end user, who would understand the decoded information in accordance with the

4 An informative summary of the debate on how speeds above thirty kilometres per hour may affect the human body, how the images of a rapidly passing landscape are processed by the human senses, and several other pathologies of a railroad trip can be found in Schivelbusch 2000.

5 The ultra-long waves (106m) of telegraphy/telephony were followed by the long (103m), medium (102m), short (101m), and ultra-short waves (100m) used for radio transmissions, finally culminating in television waves, which are again reduced by a factor of ten (10-1m). For an interesting overview in tabular form see Amereller (1994:17)

meaning initially intended by the sender.[6] Prior to the 1740s, connections and reachability were restricted by the speed limits of the horse carriages used in these times. In the 1940s, on the other hand, the respective technologies had already undergone lasting changes and transformations, making them more or less unlimited or boundless with regard to speed, signals, and information.[7]

New Computer Technologies

While the first group of new information and communication technologies had already brought substantial changes to society and every-day life, the second technological species would turn out to have an even larger impact. This second group of technologies started to emerge in the 1940s, set off by the development of the first functioning prototypes – the ENIAC in Philadelphia, the JONIAC in Princeton, etc.[8] Several places in the United States and in Europe simultaneously worked on electrifying and thus accelerating elementary arithmetical operations.[9] The basic set-up or design of these electronic calculators or computers had already been summed up as early as 1945 by John von Neumann (cf. e.g., von Neumann 1958). These computers had to have an input/output interface, through which the user was able to interact with it, a certain amount of memory or storage capacity, and a central processing unit (CPU), where the elementary arithmetical operations were carried out. From an evolutionary point of view, these new computers exhibited a number of spectacular features.

Probably the most significant feature was that even the earliest prototypes already consisted of two different parts, an internal program and operations unit and a peripheral unit to be used for the interaction between man and machine. This is clearly the most important turning point on the technological path towards self-reproducing machines, which was again explicitly initiated by John von Neumann, especially in his book about self-reproducing automatons, which was published after his death (von Neumann 1966). Another characteristic quality of this first generation of computers was

6 For a classic portrayal of the basic set-up see also the graphical overview in Shannon/Weaver 1998, 7 and 34.

7 For an interesting compilation about to the various approaches applied in media theory to identify, describe, and explain the respective changes and new breakthroughs see Pias *et al.* 1999.

8 To read about an interesting episode from the 19th century, namely Charles Babbage's attempt to design and construct computers, see Dotzler 1996.

9 Some notable overviews of the early history of computer construction can be found in Aspray 1990 and Ceruzzi 1998; or of systematics in Herken 1994.

that they linked logical calculations with electronic circuits. By the end of the 1930s it had become possible, for instance, to express elementary logical operations like "and", "or", etc. in a specific circuit language.[10] Still another characteristic lies in the digital coding and programming of these new computers – and thus in their discrete mode of operation. Finally, there was also a somewhat counter-evolutionary trend towards miniaturisation – both the outer dimensions of computers and the size of their processing units have continuously and substantially decreased in the years and decades after 1945. Over time, these computers have been transformed from dinosaur-like contraptions, which often filled several rooms, into room-size mainframes, followed by minis, all the way to the level of personal computers, notebooks – and *beyond*. [11]

During the course of only two decades – from 1940 to 1960 – this computer generation had evolved from a prototype status to a phase in which industrial production had become possible and feasible, thereby ending the long-lasting predominance of mechanics and the written word in society and introducing a new basic societal architecture, the so-called Turing creature" and more generally, the "Turing society".[12] But there were also already signs of another imminent development. This even newer generation of computers did not only have an immensely high potential for propagation to other parts of society, but it also managed to revolutionise the existing information and communication technologies – and, besides, to advance with a speed and power that had until then been unknown in the history of technology.

Changes in the Organisation of Science

Along with the emergence of various new fields of technology one can also observe a process of growth and differentiation within the sciences *per se*, which was concisely summed up as a transformation from little science to big science (cf. esp. de Solla Price 1974). In the long term, the science system had moved at a comparatively high speed – with doubling times as little as fifteen years – along an exponential curve that had been stable for several decades.

10 For more information on this topic see the very well-done descriptions in Hobart/ Schiffman 1998, 205–226.

11 Another counter-evolutionary movement of these Turing creatures ought to be mentioned here as well: At first, the programs were characterised by high-level knowledge representations and the search for logical derivations, heuristics, and combinations. Only in later stages would these Turing creatures acquire the necessary senso-motoric skills, and only in the very last stage would they be able to reproduce themselves.

12 For a more detailed description of the term "Turing societies" see Müller 1999, Müller/ Purgathofer/Vymazal 1999, or Müller 2000 and 2001.

Generally speaking, after 1945 the dream of everlasting prosperity (Burkart Lutz) was thus coupled with an over-proportional increase in growth within the scientific system itself. The following four items can be named as specific characteristics of this particular period of growth.

The first important characteristic is the extremely large extent, to which the field of science diverged from the rhythm of the general upturn in the 1950s and 1960s, as well as the specific dimensions it was embedded in during this very unusual wave of expansion – the total expenditure … on research and development amounted to three billion dollars in 1950 and 13 billion in 1960 – more than doubling every five years. The increase of 15 % each year ought to be compared to an increase of the gross national product of only 3½ % (de Solla Price 1974:104).

But this immense growth spurt in research and development can also be illustrated by means of other indicators. In 1938, 28.000 scientists were known to be "American Men of Science", whereas in 1960 their numbers had already reached 96.000 (de Solla Price 1974:48). In 1938 there were 220 scientists for every million Americans, in 1960 there were already 480, etc. During this decade, it was especially the American sciences that dreamed this dream of everlasting prosperity most strongly, intensely, and longingly.

The different methods of practical applications within the sciences themselves also started to shift permanently under the auspices of this critical growth phase: One specific feature was the emergence of big science in the sense of large-scale research units and laboratories, especially in some areas of physics and medical technology. Yet this overall increase in growth also went hand in hand with another phenomenon, which can be described as a permanent creation of small disciplinary niches, a rapid spreading of various kinds of little sciences, visible institutes and invisible faculties, som with only minimally equipped laboratory conditions.

In the 1960s we finally find first important socio-scientific visions and analyses indicating that, in principle, modern societies in fact transform themselves from industrial and transportation bases towards knowledge and communication and, thus, to post-industrial societies.[13] The George B. Pegram Lectures by Derek de Solla Price, dealing with the topic of "Little Science, Big Science", were given in 1962, right in the midst of the immense and radical changes and expansions taking place in the sciences.

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13 A little later, but still in the 1960, economics and the social sciences also started to focus more closely on these changes, with the first fundamental diagnoses presented by Fritz Machlup (1962), Daniel Bell (1968), or Amitai Etzioni (1968).

Knowledge Bases

The first generations of sender/receiver-based information and communication technologies, such as the telegraph, telephone, radio, and television, the initially rather slow increase of "Turing creatures", and the transformation of little science into big science also brought about some significant changes and shifts within the knowledge bases *per se*. If the scientific landscapes are, in a bold and simple manner, divided into normative domains like mathematics, statistics, logic, or ethics and into empirical fields, each of these two areas underwent a number of very characteristic transformations.

Since the beginning of the 20th century, the normative sciences – logic, mathematics, ethics, etc. – have been expanded and augmented by various new levels and frameworks. In mathematics, for instance, one can observe the transition from David Hilbert's vision of a fully self-contained mathematical axiomatics at the turn of the century to a state of necessary incompleteness and to an algorithmic re-definition of effective calculability by Church, Kleene, Gödel, Herbrand, Post, and Turing. This brought about a radical paradigm shift, in which the basic architecture, the potentials, but also the necessary boundaries, i.e. the blind spots and unavoidable limitations of arithmetical or deductive operations could be clearly identified and established. In the field of logic, for example, one finds a multiplication of logical systems between 1910 – when Bertrand Russell and Alfred N. Whitehead's "Principia Mathematica" was first published – and the 1930s, 1940s, and 1950s, which had taken the shape of many-valued logic, inductive logic (cf. e.g., the rather voluminous edition of Carnap 1950), modal logic, deontic logic, and many others.

The empirical sciences experienced a gradual shift of gravity and focus within the period of 1940 to 1960, thus successively ending the Golden Age of physics of the preceding four decades. After a few years of hectically searching for a unifying pattern, the basic structure of the genetic code was decoded in 1953, finally making it possible to translate it into the language of biology and subsequently into bio-technology.[14] Just like the planetary structure of the atom proposed by Ernest Rutherford at the beginning of the 20th century, Francis Crick and James Watson's discovery of the DNA structure was an important starting point, which would turn out to be the beginning of a gradual rise of biology or, more generally, the life sciences as a new leading discipline. Physics, as a key field, maintained its status as an area of large-scale research and a complex of mainly big science. From a technological

14 For James D. Watson's own account of the story, which is also quite thrilling from a historical point of view, see Watson 1970.

point of view and in terms of its basic models and mechanisms, however, it slowly started to lose ground to a very extensively structured biological or life science field, which comprised, among other components, large parts of brain research, physiology, and medicine.[15]

Another characteristic feature of the scientific landscapes of that time lay in the new connections between formal and natural sciences, which had been established between 1940 and 1960. In those years, the key empirical disciplines achieved a substantial number of formal syntheses, which eventually led to a re-definition of their basic theoretical foundations. In 1943, for instance, Warren McCulloch and Walter Pitts developed a model of the neuron and the neuronal connections, which was strongly based on Carnap's system of logic.[16] At the end of the 1930s, Claude E. Shannon transformed logic, which was originally expressed by Boolean algebra, into a circuit language (Shannon 1940). Moreover, the Turing machine constructed in 1936 could clearly be seen as the godfather of the new computer generation that started to evolve about ten years later. The structures and forms of the Bourbaki group became a central point of reference in the formulation of developmental psychology.[17] Finally, John von Neumann and Oskar Morgenstern used logic and strategic interactions to formalise game theory (von Neumann/Morgenstern 1944). Logics and linguistics also led Noam Chomsky to develop new syntheses in the field of generative grammars (Chomsky 1957, 1964, 1965) – and this is by far not the end of the list. Compared to thirty, or even sixty or a hundred years ago, the world of science had also considerably changed with regard to its disciplinary foundations and its boundaries.

The large number of intra-disciplinary syntheses of formalisms with unique empirical contents in each individual discipline leads to the assumption that the potential for inter-disciplinary and trans-disciplinary connections must have increased as well during these decades. And indeed, not only was there a major increase in the specialisation and in the sub- and sub-sub-

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15 In this connection, it should be pointed out that even such basic operations as the laboratory conditions are very different in physics and biology. For more information see, e.g., the excellent empirical overview in Knorr-Cetina 1999.

16 It strikes as rather interesting that this pioneer work by McCulloch and Pitts only contains three references to other publications, all of them dealing with logic – to Rudolf Carnap, to Hilbert/Ackermann, and to Russell/Whitehead (cf. McCulloch/Pitts 1988:39, orig. 1943)

17 For an overview see Piaget 1973 and 1983. Piaget defines the common structuralist reference point of the Bourbaki group as follows:
"The Bourbaki method was such … that they used isomorphisms to identify the most general structures, to which all kinds of mathematical elements can be subordinated, regardless of their nature and of the area they come from". (Piaget 1973:24)

compartmentalisation of larger disciplines after 1945, but the inter- and trans-disciplinary linkages and programs experienced an unexpectedly large boost as well, especially between 1948 and 1958. In the 1920s and 1930s, the conditions under which it would become possible to obtain a unified science were still limited to a few, comparably simple basic operations, namely to the creation of a unified logic of scientific languages and to the development of a common observation language – a "thing language", as Rudolf Carnap calls it – that could be applied in each discipline. But around 1950 the potential for a new and more integrative cluster of inter- and trans-disciplinary programs has increased dramatically.

10.3 New Inter- and Trans-Disciplinary Syntheses

During the 1940s intensive search processes for new inter- and trans-disciplinary programs and paradigms have set in. On a newly found level of abstraction, these inter- and trans-disciplinary approaches now focused on a common description and a homogenous modelling of the world, whereby the respective tools and methods – i.e. systems theory, information theory, cybernetics, and cognitive sciences – experienced the most significant period of inter- and trans-disciplinary propagation in the short decade between 1948 and 1958.

Systems Research

The first, and probably most abstract, inter- and trans-disciplinary program was conceived within the field of biology, which in the wake of the Darwinian synthesis also aimed to differentiate itself from common physical ensembles and to focus on specific characteristics of biological configurations. At first, the rather momentous differentiation effort went unnoticed in Central Europe, since both theoretical biology and the Gestalt-psychology in Berlin[18] viewed the specific characteristics of biological systems on the basis of how they transport material and energy and how they maintain their order and organization. Under the heading of open and closed systems, a terminology and a model core of self-regulating biological systems was developed – mainly

18 For more information see the still very interesting description by Wolfgang Köhler, who proposes that one essential feature of biological systems is that they maintain themselves as far away as possible from the state of thermo-dynamic equilibrium (cf. Wolfgang Köhler 1969:62, orig. 1938).

after Ludwig von Bertalanffy's move to the USA –, whose relevance should quickly come to reach far beyond the original domains (cf. Bertalanffy 1968). This added systemic surplus value already found its obvious organisational expression in 1954, when four people during a research assignment in Palo Alto – Ludwig von Bertalanffy (biology), Kenneth Boulding (economics), Anatol Rapoport (mathematics), and Ralph Gerard (physiology) – decided to found the "Society for the Advancement of General Systems Theory". Later on, in 1956, the aforementioned group – together with the psychologist James G. Miller and the anthropologist Margaret Mead – changed this society for system-theoretical advancement into an "International Society for the Systems Sciences" (ISSS). Subsequently, the first inter- and trans-disciplinary initiative gained an unexpected and most probably unintended level of significance within only a quarter of a century. Specific aspects that contributed to the transformation and success of systems theory should be noted in particular. One can clearly see that systems theory, which originated from the field of biology, spread very quickly to all kinds of other disciplines. Yet this expansion to new and additional fields of application also went hand in hand with a certain loss of depth, since during the course of its diffusion systems theory was gradually being turned into a universal form of description and depiction – a systemic language – for all kinds of scientific topics. This systemic language had a seemingly natural appeal and constituted a self-organised follow-up to the old idea of a common unity language for the entire scientific realm. And despite some variations among individual disciplines, the systemic language became the "lingua franca" for most scientific areas. An early reader with classical texts on systems research, which was published in 1969, only deals with the core and the environments of open systems where organisational research and management appeared clearly as secondary topics only (Emery 1969). When the second volume was published in 1981, again under the significantly general title "Systems Thinking", it likewise contained some basic systemic texts but now also included several contributions on individuals and groups, communication, ecosystems, government and controllability, etc. (Emery 1981). Following this trend, a little more than twenty years after the establishment of a primarily biologically oriented general systems theory, a conference was held in Versailles, for instance, about "New Trends in Systems Analysis", discussing such topics as the "Control of Distributing Systems", "Industrial Robots and the Application of Micro-Processors", "Systems Analysis and Energy", "Economy", as well as "Environment and Pollution" (Bensoussan/Lions 1977). Regardless of this new and universal systemic mode of description, however, a small repertoire of models and research efforts still focused on finding universal laws, patterns and mechanisms that

could be applied in any number of disciplinary fields – a universal theory of systems. But this more theory-laden direction was to lose most of its significance within the 1960s and 1970s and would reach its logical peak only in Spencer Brown's work and with little immediate resonance.[19] Another specific characteristic of early systems research is the idiosyncratic role that was taken by theoretical sociology in this context. Already at a very early stage, in 1951, Talcott Parsons presented his draft on social systems, which would – among other things – also have a large effect on the establishment of US-based sociology schools throughout the fifties.[20] Yet this branch within systems research likewise turned out to be an evolutionary cul-de-sac – soon to be replaced by systems-free alternatives in the 1960s – and was seen as a rather obstinate marginal area even within systems research itself.[21]
But all in all, the establishment of systems research between 1948 and 1958 has indeed brought a new inter- and very weak trans-disciplinary set of descriptive and explanatory tools across the disciplinary landscapes.

Information Theory
The second important inter- and trans-disciplinary interface was set up in the areas of information and communication technologies, computer architecture, and thermodynamics. The specific location of this new development was rather typical, as this inter- and trans-disciplinary innovation took place within the "Bell Laboratories" – one of the major brain trusts for information and communication technologies that existed in these days. In 1948, two articles were published in the "Bell System Technical Journal", followed by a book in 1949, which in addition to the two aforementioned articles contained a commentary by Warren Weaver as an introductory chapter. These articles and

19 Towards the end of the 1970s, Mario Bunge published his two-volume edition about ontology and systems language, which was, for the time being, a summary of all systemic terminology as well as of its application in different areas, including the self-application to conceptual systems. By the beginning of the 1980s, various collections on this topic had started to include other fields as well, such as biomedicine, engineering, offshore structures, non-linear programming, traffic and transport, economic sciences, and many others (Balakrishnan/Thoma 1984).

20 It almost seems that sociology traditionally used and participated in these changes within the systems program rather selectively. The biologically inspired theory pertainig to autopoietic systems, for instance, was also taken up in a thoroughly unique and idiosyncratic manner by Niklas Luhman (1984), to be exact – and should just like Parson's synthesis become highly significant within the field of sociology, yet not within systems research.

21 Stafford Beer's overview of the most important approaches in systems research, for example, doesn't even mention Talcott Parsons' work (cf. the diagram arranged in concentric circles in Stafford Beer 1994b:570, orig. 1979).

the small booklet did provide the theoretical foundations for the so-called information theory, whose basic terminology and measuring operations were, on the one hand, based on thermodynamics and which, on the other hand, set down important rules, restrictions and design principles for the new information and communication technologies – as for instance Shannon's two theorems on the connection between codes and channel transmission capacities (cf. also Khinchin 1957:102ff.). And over the next ten years, i.e. between 1948 and 1958, information theory came to be the standard apparatus for measuring, calculating, or designing not only in the existing information and communication technologies, but for the new generation of computers and for other scientific disciplines as well. The following aspects seem to be particularly noteworthy in this context:

First of all, it ought to be pointed out that this new kind of science emerged at the interfaces between information and communication technologies and thermodynamics, with the primary aim to transfer and exchange signals irrespective of heir semantic content. In his introduction to the aforementioned booklet, Warren Weaver lists three different problem levels that exist in the area of communications research and clearly classifies Shannon's information theory as belonging to the first, the technical level – "How accurately can the symbols of communication be transmitted (the technical problem)" (Shannon/Weaver 1998:4). Another characteristic feature of the new information or, to be more exact, of the new signal theory is the fact that the basic principles were conceived and formulated in several different places, albeit in a very similar manner – in the laboratories of Bell Telephone, by Norbert Wiener at the Massachusetts Institute of Technology and by Andrej N. Kolmogoroff at the University of Moscow. Another key aspect is that the information theory was almost immediately linked to the new computer technologies, as it became obvious that especially the digital binary coding of these computers would be an ideal field of application for this theory. Finally, the information theory rapidly gained the status of an inter- and trans-disciplinary perspective, which was further developed in collaboration with many disciplines within the natural or the social sciences. W. Ross Ashby, one of the greatest pioneers of his time, who was also a fellow researcher at Foerster's "Biological Computer Laboratory" (BCL) in the 1960s, came up with a huge amount of information-theoretical ideas and questions that extended far into every-day human life. W. Ross Ashby, for example, speculated about the amount of information contained in the following activity, which was obviously carried out by a male subject:

He walks across the room to his book shelf (avoiding a chair that is in his path), finds his French Dictionary (among 100 other books), finds the word, reads the English translation, and writes down the corresponding word. (Ashby 1968:191)

After sequencing this activity into nine different elements, Ashby carried out an information-theoretical assessment of each of these components (e.g., "walking 10 paces on two legs while maintaining normal velocity" or "selecting a path to avoid collision with the chair") and obtains a result that actually turns out to be highly counter-intuitive.

The most surprising feature of the final result was, to us, the smallness of the number: 169 bits for about a minute's activity, or 3 bits per second. (ibid.)

Thus, every imaginable door had been thrust open to the possibility of a monitoring and measuring with the help of the new information theory in areas as heterogeneous as the new information and communication technologies, the rapidly expanding computer generations, the interfaces between man and machine, and even the human dealings and routines of every-day life.

Cybernetics

While systems theory in its course of evolution represented a homogenous method to describe highly heterogeneous areas and the information-theoretical program provided a homogenous measuring device especially for the newly arising technologies, there were still no homogeneous models, mechanisms, and patterns that would be equally relevant in such fields as physical biology, psycho-physics, or biomedicine. Interestingly, the first group of models also came into being in 1948 – when Norbert Wiener's book about "Cybernetics" was presented, fresh from the printing presses, to an interested inter- and trans-disciplinary public. (Considering the observations made in the previous chapters, already the subtitle of the book strikes as being highly characteristic – "Control and Communication in the Animal and the Machine".) This third inter-and trans-disciplinary synthesis, which mainly focuses on models of control and regulation, was thus firmly anchored in the new arena of information and communication technologies, the new Turing machines, and biology. The cybernetic initiative mainly emerged during a series of conferences, which were organized about once a year by the Josiah Macy Jr. Foundation, with the first one being held in New York City in May 1942 (for a historical overview see esp. Heims 1991). Representing a kind of cognitive parallel movement, the first few Macy Conferences had already started to bring new artificial as well as natural models and mechanisms from brain research or information and communication technology into the limelight. A great leap forward was undertaken at the Macy Conference on March 8th and 9th, 1946, which mainly dealt with "Feedback Mechanisms and Circular Causal Systems in Biological and Social Systems". John von Neumann, for example, spoke on the basic architecture of the first electronic computer generation that was being built at the time, and Rafael Lorente de Nó presented an overview of the "Nervous System as a Computing Device". During the course of these two days, the attending circle of friends of circularities came to realize that these newly conceived mechanisms of feedback and target-oriented systems had a surprisingly wide range of application within biological and social systems. Starting with the sixth Macy Conference, which took place on March 24th and 25th, 1949, in the Beekman Hotel in New York, the different contributions and discussions were also made available in book form. And already the first volume, published in 1950 under the title of "Cybernetics. Circular Causal, and Feedback Mechanisms in Biological and Social Systems", saw Heinz von Foerster fully integrated as a secretary and editor. The tenth Macy Conference, which was said to have been rather turbulent and chaotic,[22] not least because of the increasingly serious divergences of opinion between Warren McCulloch and Norbert Wiener, marks the end of this string of conferences. In the years to follow, cybernetics would be propagated by other means of scientific organisation, by journals, conferences and scientific societies. Again, there are four specific traits that make this regulation and control approach stand out on the larger inter- and trans-disciplinary reference frame.

The first characteristic of the new regulation-based model program is the fact that it was primarily technology-oriented, initially with a strong focus on the new information and communication technologies and later on, with a somewhat weaker focus, on the new computer technologies. Another striking feature of cybernetics is its close alliance and symbiotic relationship with information theory, whereby the latter provided the basic theoretical measurement tools and procedures for the design of self-regulating, target-oriented automatons. The third outstanding characteristic is the large number of follow-up mechanisms and models, which can be applied to regulation and control processes in various fields. In W. Ross Ashby's classic "Introduction to Cybernetics", for example, one can find several significant regulation mechanisms, such as the "law of requisite variety", "regulation by disturbance or deviation", but also a description device for complex systems as a whole. (Ashby 1956). Finally, it needs to be said that the significance of cybernetics in the social sciences turned out as surprisingly high, and especially the political regulation theory made ample use of the new analytic potentials offered by this new field quite early on. The management and organization theory was also

22 Interestingly, the respective debates were not included when the contributions from the Macy Conference were re-published in 1955 by Heinz von Foerster, Margaret Mead, and the psychologist Hans Lukus Teuber.

soon to be structured and styled in a more cybernetic manner. Therefore, it is likely not just a mere coincidence that two fundamental contributions in these two areas operated with very similar metaphors and were published under nearly the same title – Karl W. Deutsch's "The Nerves of Government" and Stafford Beer's "Brain of the Firm". In addition, it should be mentioned as well that in 1985 the "cybernetic synthesis" would also be introduced – under the key word of "cyborgs", i.e. "cybernetic organisms" – to the post-modern and to the feminist discourse (cf. esp. Haraway 1995).

At any rate, between 1948 and 1958 cybernetics was clearly established as an important resource of inter- and trans-disciplinary modeling tools across scientific disciplines in the natural and in the social sciences.

The Cognitive Sciences

The decade between 1948 and 1958 witnessed the rise of yet another initiative which was concentrated more strongly on patterns, and mechanisms of brain and thought processes. The focus of this fourth inter- and trans-disciplinary approach was, again, mainly on the new generation of computers – but this time mostly on their functionality and their potential for being used as thinking machines. Drawing from computer technologies, brain research, logics, and psychology, the main aim in this context was to obtain an improved understanding on the trinity of thought, intelligence, and cognition. Once more, 1948 proved to be of great significance, when in September a group of neurologists, cyberneticians, and computer scientists met at the California Institute of Technology to discuss "Cerebral Mechanisms in Behaviour".[23] At the so-called Hixon Symposium, which was opened by John von Neumann and Warren McCulloch, the Harvard psychologist Karl Lashley made a programmatic speech on "The Problem of Serial Order in Behaviour", which is generally said to have sparked the birth of neuropsychology. Lashley's address could be seen as a strong plea for a paradigm shift from a trivial perspective, emphasising environment-reaction sequences to a non-trivial point of view, which adds an additional element of internal state determination – the I and its brain – as a central descriptive and explanatory component. Along the lines of this counter-behaviourist approach, Donald E. Hebb proposed a learning mechanism for neural networks in 1949, which culminated in the so-called Hebbian theory or Hebbian learning. When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in

23 For further details see the highly informative portrayal in Howard Gardner 1985, which includes a very comprehensive overview of the different developments since the 1950s.

one or both cells so that A's efficiency, as one of the cells firing B, is increased. (Hebb 1949:50) In 1950, Alan Turing took on several serious objections to the possibility of artificial intelligence in digital computers and sequentially refused every single argument that might have halted the construction of thinking machines. He proposed some subtle testing conditions – i.e., two imitation or deception games – to determine whether a machine was capable of intelligent conversational behaviour. Even now it seems utopian or implausible, that any machine or computer could pass the Turing test and thus be considered intelligent (cf. e.g., Hodges 1983). In 1952, the first edition of Ross W. Ashby's "Design for a Brain" was published, in which he synthesised all the neuronal mechanisms hitherto known and summarised them in a rather dynamic manner. The take-off of the cognitive sciences eventually took place in September 1956, initiated by a conference on information theory at the Massachusetts Institute of Technology, which paved the way for some new research directions that have very little resemblance to the tools and analytical frameworks of information technology. Two contributions, in particular, turned out to play a pioneering role in the subsequent developments: Allen Newell and Herbert Simon's overview of the "Logic Theory Machine", and Noam Chomsky's "Three Models of Language". *Pars pro toto*, it seems fitting to quote the psychologist George A. Miller, also known for his involvement in systems theory, who sums up his main impressions of this meeting as follows:

I went away from the Symposium with a strong conviction, more intuitive than rational, that human experimental psychology, theoretical linguistics, and computer simulation of cognitive processes were all pieces of a larger whole, and that the future would see progressive elaboration and coordination of their shared concerns. (Gardner 1985:29)

Thus, a fourth inter-disciplinary synthesis was established, which became increasingly significant in the 1960s and 1970s, sailing under the flag cognitive science and – more specifically – under artificial intelligence, and which made it possible to expand and further develop the repertoire of both inter- and trans-disciplinary methods and models under the leading perspective of cognition, thought processes, and intelligence. Consequently, this fourth synthesis eventually brought forth cogrobs, i.e., cognitive robots, a homogenisation between the new computer generations and the programs developed for them, the rapidly expanding programming languages, logics, algorithmic linguistics, brain research, and cognitive psychology. The following points are especially important at this fourth inter- and trans-disciplinary interface:

While cybernetics primarily served as a model resource for the information and communication technologies and sometimes also for the new computer generations, the opposite is the case for the cognitive science program. Here the main emphasis was on the models and mechanisms pertaining to the new generation of computers, whereas the existing information and communication technologies play a rather peripheral role. As far as this linkage between machines and neuronal models is concerned, it ought to be pointed out that due to the basic architectural differences – serial on the one hand and parallel on the other hand – this connection was charged with a lot of tensions and remained somewhat precarious for quite a long time.[24] Nevertheless, this gap started to grow smaller in the 1980s when new, more homogeneous approaches began to emerge. Another distinctive quality is the fact that this cognitive science platform was dominated by top-down approaches or symbol-based programs until far into the 1980s, which were eventually, albeit at a rather late stage, replaced by bottom-up architectures.[25] The third characteristic and likewise one of the most momentous lines of thought within this synthesis can be summed up as a slow departing from the cherished notion of a mind's separate I. Not least because of the many-layered meaning of this term, which among others also includes the user illusion of the self (Tor Norretranders), the most mindful and self-conscious sceneries within the Cartesian theatre had over the years, but especially from the 1990s onwards, been pushed to the outer margins of the stage and taken up by every-day folklore and folk psychology. Daniel C. Dennett's book, *"Consciousness Explained"* (1991), may well be seen as a sufficiently provocative indication of this far-reaching departure from one's I as central processing unit. The social sciences themselves – as a last characteristic feature – largely stayed away from these cognitive science syntheses, and not until very late and to varying degrees in different regions – moreso in the United States, less so in other countries – did they begin to get engaged in or linked to these new inter- and trans-disciplinary programs on thought.

In any case, the cognitive sciences, which emerged between 1948 and 1958, provided the different scientific disciplines with yet another set of inter- and trans-disciplinary modelling tools.

24 It should be noted that one of the main activities at the BCL consisted of bridging this gap by devising parallel architectures, both in theory and practice. For further details see, for instance, Heinz von Foerster's important but at the time mostly unnoticed article about "Computation in Neural Nets", which was published in 1967.

25 Informative overviews of early designs from the late 1950s and 1960s can be found, for example, in Herbert Simon 1977 and 1985, or in Langley/Simon/Bradshaw/Zytkow 1987.

Additional Integrative Perspectives

At the end of the 1950s, there were also several other inter- and trans-disciplinary activities taking place at various interfaces between Turing architectures, cybernetics, cognition, biology, and – of course – systems research, which would in turn strengthen the newly emerging foursome of systems, information, cybernetics and cognition. Some of these efforts, including conferences, research projects, and conference reports, for instance, were for the first time presented to the public under the name of bionics at a three-day event held in Dayton, Ohio from September 13th to 15th, 1960. Quite in the spirit of the newly established inter- and trans-disciplinary reference frame, Heinz von Foerster explained in his introductory speech the purpose of this meeting as follows:

'Who is the baby?' An innocent onlooker of these festivities may rightly ask, 'Why this fuss?' The answer to these questions is very simple indeed: This symposium sets an official mark for the end of one era of scientific endeavor and, at the same time, beginning of a new one: Specialization is 'OUT', Universalization is 'IN'. (Foerster 1960:1)

The bionics approach can in a few brief words be characterised as a perspective that considered the search for living prototypes to be a key factor in the discovery and invention of new technologies. Bionics mainly focused on analogies, the formation of common patterns and possible transfers between natural designs and artificial constructs. It is well known that the few years before and after 1960 were brimming with parallels drawn between natural and artificial systems.

The list of activities within the new inter- and trans-disciplinary reference frame could be much longer, particularly if one also includes the smaller connections branching out towards biology, linguistics, or other areas such as operations research. At this point it should be sufficient to stress the existence of additional integrative programs which helped to strengthen the main quadriga of systems, information, cybernetics and cognition.

The Biological Computer Laboratory

The time seems to have come, in which the paths of intellectual research in highly heterogeneous fields have started to converge towards a common point of origin. We now reconcile/combine the differentiations we made earlier. Problems in physics are of a philosophical nature, biology and psychology make use of physical methods, and medical research is closely linked with fundamental biological questions. (Foerster 1948:VII) The man, who proposed an inter- and trans-disciplinary re-combination and merging in 1948, had not, as it is usually the case, already reached the end of a successful and long professional life in the sciences, but was at most – at least by the standards and etiquette of the times – at the beginning of a still rather unlikely academic career. The man, who found it completely natural to postulate a common origin as the up-and-coming program for scientific research, had hitherto neither drawn attention to himself as a universalist between physics and philosophy nor as a bio-medical researcher, but can rather be described as an extremely versatile person with identities that went beyond science – having been a magician once, or a mechanic – who worked in two other professions outside university circles – as an electronics engineer and as a factotum in various matters of culture and science at "Rot-Weiß-Rot", a broadcasting company that had been set up in Austria after World War II.[26] The man, who – somewhat oddly – wrote about "the differentiations *we* made",[27] had hardly played a part in these differentiations and classifications, as he had only published very little by then, i.e., only one small and very specialized article essay in 1943 in the Journal of the Lilienthal Society.[28] And finally, the man who composed these lines could in a very important sense not have known what he was writing about, because the foundations for this common origin had clearly not yet been in place as early as 1948: These new homogeneous programs were still under construction, so to speak. Yet in spite of the unfavourable conditions in Vienna and the surrounding area, the author of this quote – Heinz von Foerster – produced a booklet about memory, whose content could – and certainly *should* – magically catapult him right into the core of the inter- and trans-disciplinary innovations and restructuring activities taking place at the time in Princeton, Cambridge, or Urbana. But it was especially the "Biological Computer Laboratory" (BCL) founded in 1958 by Heinz von Foerster that stood out among these new initiatives, mainly because it was organised as an inter-and trans-disciplinary

26 In a report, which Heinz von Foerster alias "Dr. Heinrich" presented to the "Rot-Weiß-Rot" broadcasting company on December 7th, 1948, he listed for the time between 1946 and 1948 a total of 213 written, 247 produced, and 296 controlled radio broadcasts, and a total of eight different modes of transmission – including scientific programs, theatre and industrial reports, and daily up-to-date reports (Heinz von Foerster Archive, "Scrapbooks", Vol. 1).

27 With such phrases one is likely reminded of the first two steps in Zen Buddhism – the "sho chu hen", meaning "that the one is in the many … the infinite is in the finite, etc". (Fromm/Suzuki/Martino 1971:82) and the "hen chu sho", meaning that "when the one is in the many, the many must be in the one" (ibid:82f.)

28 More precisely, Foerster stated that the essay was about Klystron, an electronic component, for which "the highest efficiency and the most effective output" was to be obtained (Foerster 1943:1).

laboratory which was meant to incorporate each of the four existing inter- and trans-disciplinary syntheses and directions. In some way, it was set up right at the interface of interfaces, at the point where all the new computer technologies, the information theory, cybernetics, and cognitive sciences converged. Quite interestingly, the term systems can already be found in the meetings and programs of the early Macy Conferences and it has become, quite naturally, also part of the Foersterian language repertoire.[29]

Therefore, it is hardly surprising that only two years after the establishment of the BCL Heinz von Foerster already drew attention to himself in this wave of new syntheses for making a first, substantial contribution in this context. In 1960, the BCL organised a conference on the "Self-Organisation" of systems, which dealt with the basic patterns and mechanisms of order creation and order maintenance. The line-up of participants included well-known inter- and trans-disciplinarians like W. Ross Ashby, Stafford Beer, John R. Bowman, Warren McCulloch, Anatol Rapoport, Roger Sperry, and many others. Heinz von Foerster also introduced a novel viewpoint into the debate on self-organisation – initially in a paper written in 1959 –, which would turn out to be of great importance for the future – namely the creation of order through disturbance, i.e. order from noise.

In my restaurant … self-organising systems do not only feed on order, the menu for them also contains disturbances … Therefore, I'd like to name two mechanisms that are important keys to the understanding of self-organising systems: following Schrödinger's suggestion, we can call one of them the principle of 'order from order', the other one the principle of 'order from noise' (Foerster 1985:125ff.).

Consequently, the research carried out at the BCL began to shift towards a perspective that would begin to put more and more emphasis on epistemological issues. During the course of only a few years, the collaborative efforts of Warren McCulloch,[30] Humberto Maturana (1985), W. Ross Ashby, Heinz von Foerster, and other co-researchers at the BCL would lead to a

29 This feat, which he himself once called his "most risky experiment" and "conjuring trick", was only made possible by a combination of a number of lucky chances and coincidences: His extensive general knowledge in science and culture, for instance, which was conveyed to him by his parents and his studies at Viennese universities, an outstanding cognitive capacity for drawing analogies, and a general lightness of trans-disciplinary being, i.e., a profound talent for designing and implementing all kinds of inter- and trans-disciplinary recombinations.

30 In 1964, Warren McCulloch wrote an important programmatic essay entitled "A Historical Introduction to the Postulational Foundations of Experimental Epistemology" (McCulloch 1988b), which was published within the context of the Wenner-Gren Foundation.

momentous epistemological and practical expansion of the existing inter- and trans-disciplinary platforms by incorporating the observer who was to become an integral component within this new inter- and trans-disciplinary research design. And, generally, one will surely agree with the statement made by Katherine Hayles, who saw the main significance of the BCL in its attempt to help artificial life, algorithmic thinking, and artificial intelligence obtain reflexivity, self-referentiality or, *horribile scriptu*, self-awareness. (Hayles 1999:131ff.).

All things considered, it can thus be said that at least after 1958 Heinz von Foerster's "Biological Computer Laboratory" clearly brought another inter- and trans-disciplinary set of modelling instruments to the disciplinary landscapes of the United States.

Trans-disciplinary Perspectives for Explaining the World

Within only one decade, the four inter- and trans-disciplinary programs pertaining to the language of systems, the theory and measurement of information, models of control and regulation and cognition patterns managed to form a coherent and re-combinable reference frame that provided the necessary tools and instruments for operations of disciplinary research. A great number of disciplinary fields could now be portrayed and described systemically, they could be measured through information-theoretical dimensions, and modelled by means of cybernetic or cognitive mechanisms. It is therefore not surprising that the most important written contributions from the inter- and trans-disciplinary key decade between 1948 and 1958 contain and recombine elements from all four programs. Taking a look once more at the great inter- and trans-disciplinary syntheses from this period, one will notice that besides the high level of consistency and recombinatorial capacities – this new inter- and trans-disciplinary reference frame has, after all, been constantly expanded and added to for more than five decades. Equally important, there are also a number of other notable characteristics.

First of all, it is rather striking that these new inter- and trans-disciplinary connections were not set up within the hitherto established core and leading disciplines – including, above all, physics and the revolutions that had taken place within this field since the beginning of the 20th century. The inter- and trans-disciplinary efforts in the 1950s, trying to base further scientific development on elementary physics, never managed to reach beyond the status of impracticable and likewise ineffective scientific architectures.[31]

31 Cf. Nagel 1961 or Hempel 1966:101ff.

The new inter- and trans-disciplinary interfaces were preferably created in young, recently evolved segments, which also constituted the core areas of the aforementioned new fields of technology and knowledge – including the rapidly spreading information and communication technologies, the swift development of computer architectures, of new logic systems and recursive algorithms, and of biology and brain research.[32]

Another characteristic, which is also relevant from the viewpoint of innovation theory, lies in the fact that the main research foci and the directions of further inter- and trans-disciplinary research were defined within just a few years. Especially in 1948, the inter- and trans-disciplinary year of wonders, some very important contributions were published and several new research areas were established – e.g., information theory, cybernetics, the Hixon Symposium for the cognitive sciences, and Heinz von Foerster's book on memory, which would in turn become his personal "entrance ticket" to these new inter-and trans-disciplinary arenas.

Yet another distinguishing feature of these four programs is, in many different aspects, their high degree of novelty. These programs, which started out after 1945, were not based on previously available inter-disciplinary designs but rather tried to adapt, in particular, to the re-structured basic technological and cognitive conditions. With regard to content, each of the four new inter-and trans-disciplinary directions successfully managed to recombine and integrate important building blocks and elements from the new fields of technology and knowledge. And due to the great number of overlaps it is also not surprising that each of the prominent inter- and trans-disciplinarians was involved in more than just one program. John von Neumann, for example, developed the basic architecture for the new Turing machines, actively contributed to the development and propagation of cybernetics, explicitly looked for similarities and differences between the human brain and computers, and – last, but certainly not least – also produced a scientific text on game theory, thus giving birth to a trans-disciplinary set of modelling tools that would come to play a very significant role in the decades to follow. Norbert Wiener prominently featured in cybernetics, in the development of information theory, and in the debate on the fundamental principles of the cognitive sciences and metaphysical borderline questions arising in this context (cf. Wiener 1964). Warren McCulloch definitely played a pioneering role in the cognitive sciences with his logical synthesis, as a co-orchestrator of the Macy

32 This also supports the well-documented fact in innovation theory that new things develop and spread more easily on the periphery than in the centres of the respective ensembles. For more information see the overviews in Rogers 1995.

Conferences he also became one of the founders of cybernetics, and his involvement in computer technologies clearly made him an avantgardist of artificial intelligence.[33] There are still many more who could be added to this list of inter- and trans-disciplinary cross-over practitioners like Claude E. Shannon, Ludwig von Bertalanffy, Friedrich A. von Hayek, Margaret Mead, Anatol Rapoport, as well as Heinz von Foerster, who also concerned himself with these new fields of technology – mainly electronics and radio – in the early stages of his career, and who can be found, especially after 1948/49, at various interfaces between cybernetics, cognitive sciences, information theory, and systems research.

Another characteristic trait of these new inter-disciplinary designs is the surprisingly wide range and great depth of application. Regardless of the fine distinctions that are made especially in the German-speaking area between the natural and cultural sciences, each of these great visions of inter- and trans-disciplinarity could be applied nearly everywhere within the scientific system, equally affecting both the natural and social sciences.

And finally it ought to be pointed out that each of the four inter- and trans-disciplinary programs built up its own, independent research organisation comprising a certain number of inter-and trans-disciplinary connections and linkages. Due to the wide spectrum of journals (e.g., the "General Systems Journal" had become quite popular), the new institutes that had been set up to include several disciplines (e.g., the fields of systems theory, information theory, cybernetics, and cognitive sciences), or the large variety of conferences and congresses, these new inter-and trans-disciplinary initiatives managed to become irreversibly embedded as a connecting reference frame in the science system of the 1950s and 1960s.

With his Biological Computer Laboratory Heinz von Foerster had also become an important element in this wave of inter- and trans-disciplinary growth and diffusion. In 1958, he could very well have used his visionary text from 1948, albeit in a slightly altered and recombined form, in the founding documents of the BCL: The time has come, in which the paths of scientific research in highly heterogeneous fields have started to converge towards an inter-and trans-disciplinary reference frame. We now reconcile the differentiations we made earlier. Frontline problems in philosophy are of a cognitive nature, the systems in biology and psychology make use of the information theory

33 Warren McCulloch's bibliography, for instance, contains some contributions that are even nowadays still extremely interesting and visionary, such as "Machines that Think and Want" or "Towards Some Circuitry of Ethical Robots …", all of which were re-printed in McCulloch 1988.

and cybernetics, and medical or demographic research is closely linked with fundamental biological questions.

Clearly, this is exactly the program that Heinz von Foerster and his BCL team implemented quite spectacularly during the following one and a half decades at Urbana.