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## The Influence of Natural Science Theories on Contemporary Social Science

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Contents

Abstract

The purpose of this paper which was written for a forthcoming book on the state-of-the-art in the social sciences is to survey the influence which natural science concepts and models have recently had on theoretical developments in the social sciences, especially sociology. Such influences can be found both in the development of theory and in the development of empirical research. Different modes of theory transfer are assessed, and the forces stimulating the development of social theory are discussed. It is argued that the stimulation of genuine social theory building by the application of highly generalized conceptual or explanatory paradigms derived from natural science is not sufficient for the development of social theory.

# The Influence of Natural Science Theories on Contemporary Social Science

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## Abstract

The purpose of this paper, which was written for a forthcoming book on the state-of-the-art in the social sciences, is to survey the influence which natural science concepts and models have recently had on theoretical developments in the social sciences, especially sociology. Such influences can be found both in the field of formal modelling, and in macrosociological theory building. Different modes of theory transfer are assessed, and the forces stimulating it are discussed. The most fruitful effect of transfer turns out to be the stimulation of genuine social theory building by the application of highly generalized conceptual or explanatory paradigms derived from natural science theories.

\* \* \* \* \*

Dieses Papier, als Beitrag zu einem Sammelband über den gegenwärtigen Stand der Sozialwissenschaften verfaßt, will einen Überblick über die Einflüsse geben, die naturwissenschaftliche Konzepte und Modelle in jüngster Zeit auf die Sozialwissenschaften und hier speziell auf die Soziologie ausgeübt haben. Diese Einflüsse finden sich sowohl in der sozialwissenschaftlichen Modellbildung (formale/mathematische Modellierung) wie in der soziologischen Makrotheorie. Verschiedene Formen des Transfers werden unterschieden und die Kräfte, die heute die Übernahme naturwissenschaftlicher Modelle motivieren, werden erörtert. Es zeigt sich, daß die vermutlich fruchtbarste Form des Transfers dort vorliegt, wo die Übertragung hochgradig generalisierter Konzepte oder Erklärungsparadigmata aus den Naturwissenschaften auf soziale Vorgänge die eigenständige Entwicklung soziologischer Theorie anregt.

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\* The persons who in one way or another have contributed to this paper are too numerous to be listed. Special thanks are due to the participants of two workshops, one mainly composed of social scientists and the other mainly of natural scientists, where the topic of this paper was discussed. Helpful comments on earlier drafts were received from the other authors of the book for which this paper has been commissioned, as well as from colleagues at the MPIFG. The book editors, Bernd Biervert and Meinolf Dierkes, have kindly agreed to this prepublication.



### 1. Forms and Preconditions of Theory Transfer

The purpose of this paper is to evaluate recent methodological and theoretical achievements in the social sciences, especially in sociology, as these are related to the adoption of natural science methods, concepts, and theoretical models. The very definition of such a task in the framework of a state-of-the-art report implies that social science borrowing from the natural sciences has contributed importantly to social science advances. In fact, one could easily gain the impression that this is so by looking at the frequency with which terms like synergetics, nonequilibrium dynamics, autopoiesis, population ecology, etc. have been used in sociological publications, and by observing the demonstrative familiarity of social scientists with the works of such authors as Prigogine, Haken, Maturana, Thom, and Eigen.<sup>1</sup> While this may justify to devote a paper to this topic, it does not go to say that most of our recent achievements have been stimulated by natural science inputs. To evaluate means to identify, describe, and assess. While the following analysis concentrates selectively on transfers from the natural to the social sciences, the assessment of their importance for the latter is a separate issue which will be raised again in conclusion.

Scientific disciplines<sup>2</sup> have never operated as watertight compartments; the history of scientific development is replete with cases of fruitful interchange and cross-fertilization. Interdisciplinary relations can take three basically different forms. Borrowing, i.e. the transfer of methods, concepts, and theoretical models of another discipline, is the focus of this chapter. This should be clearly distinguished from processes of reductionist extension on one side and from joint ventures on the

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<sup>1</sup> It is indicative of this situation that the official bulletin of the German Sociological Society recently carried a report on the "challenge that social sciences face from natural sciences" (Bammé 1986), while a discussion about the transferability of natural science models started in one of the major German social science journals (Druwe 1988, 1989; Schöppe et al. 1989).

<sup>2</sup> This concept is here being used roughly in the sense in which Richard Whitley (1984) uses the term intellectual fields.

other. In the first case, a discipline and its explanatory claim are extended into the phenomenal domain of another discipline. This takes place, for instance, when the chemist starts to analyze and explain biological phenomena, or when the biologist tries to explain social features of modern societies as a consequence of biological, Darwinian evolution. Such processes of extension (or reductionism, if looked at from the perspective of the "invaded" discipline), can lead to the development of new specialities whose name sometimes recalls the mixed ancestry; biochemistry and sociobiology are cases in point.

Joint ventures, in contrast, are cases of genuine interdisciplinary collaboration. One important field where this takes place today is brain research, where neurophysiology and computer science cooperate, preserving their own methods and paradigms. Other fields are public health, and ecology; in the latter, natural scientists from different disciplines begin to cooperate among themselves and with economists (Brewer 1988). The necessarily interdisciplinary nature of research and theorizing in these fields is justified by the obvious fact of a strong mutual dependence between phenomena belonging to the traditional domain of different disciplines. In terms of practical relevance, it is quite possible that such interdisciplinary cooperation, as is beginning particularly in the field of ecology and public health, could well be more important than any transfer and extension efforts. However, interdisciplinary cooperation, while possibly of high problem-solving potential, does not necessarily stimulate the internal development of the participating disciplines in the same way and to the same extent as transfer efforts do. It is to these we now turn.

Whether, following C.P. Snow's image of the two cultures, one considers the social sciences to be part of the humanities, or whether with Lepenies (1985) one considers them to be a third category, straddling the fence between natural sciences and humanities (Lepenies 1985), it is evident that the relationship between natural and social sciences has been characterized by ambivalence. A century ago, at least in Germany, the cultural sciences looked down on the natural sciences whose exactness, search for simplicity, and mathematical formalization appeared a deficient, if not barbaric mode of cognition - the ignoble activity of observing the dreary repetition of

mechanical processes, to paraphrase Dilthey.<sup>3</sup> On the other hand, there have always been attempts on the part of the social sciences to emulate the natural sciences in order to overcome, as far as possible, their characteristic "softness". Where the unity of scientific method was affirmed and sociology was ranged among the nomothetic disciplines, at least the methods, if not the basic explanatory principles of the natural sciences were looked upon for guidance. This is a view which has found expression most clearly in the work of Durkheim who wanted to treat "*les faits sociaux comme des choses*". In modified form, the approaches of the humanities and the sciences, the more historical and interpretive Weberian and the more strictly nomothetic Durkheimian traditions, still coexist - possibly with a stronger emphasis on the former in political science, and a stronger emphasis on the latter in sociology. The conflict between the two schools of thinking has for some time been pushed into the background by the issue of value-neutrality, the debate between Adorno (critical theory) and Popper (neo-positivism), which, transformed into a political left-right issue, has been prominent in the social sciences after World War II. Recent attempts to apply natural science methods and theories tend to re-open the older debate about the epistemological status of the social sciences, which becomes crystallized in the issue of transferability.

There are different possible forms of transfer from the natural to the social sciences. The most basic distinction is between the transfer of methods and the transfer of substantive content, ranging from single concepts to complete theoretical models.

With respect to the borrowing of methods, it is not the techniques of data collection (e.g. experimentation) but the methods of organizing and presenting data that will be discussed here, particularly formalization and mathematization. Attempts to measure social phenomena quantitatively date back to the very beginning of empirical social research. In the analysis of quantitative data, increasingly sophisticated statistical methods have been used, from means and ratios over correlation coefficients to factor, cluster, and multiple regression

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<sup>3</sup> According to a quotation in Queisser 1987: 13.



analysis. Such quantification is a direct expression of the claimed status as an empirical discipline, and should not be considered a form of borrowing from the natural sciences. Formal and mathematical modelling, on the other hand, might be considered a characteristic of (many) natural sciences which the social sciences have started to emulate more recently.

Substantive borrowing from the natural sciences has a long tradition in sociology. Particularly common were attempts to picture society as an organism. Organismic analogies inspired Herbert Spencer and his analysis of social differentiation. From Spencer, an unbroken line of sociological theorizing about the structure and evolution of social systems can be traced to the very present. Physical analogies, in contrast, have long played a lesser role. When sociology was still in its infancy, there were references to a "social physics", but by and large the mechanical world view with its assumptions of reversibility and linearity was considered ill adapted to social reality. This changed with the ascendance of general systems theory, cybernetics, and information theory. In political science, Karl Deutsch (1963) and David Easton (1967) and in sociology the systems theory of Talcott Parsons reflect these influences. More recently, the growing interest of natural scientists in the analysis of nonlinear dynamic systems - e.g. Prigogine's dissipative structures, Haken's synergetics, or studies of "deterministic chaos" - has stimulated a new wave of borrowing from the physical sciences.

Substantive borrowing from the natural sciences can take different forms, which it is important to distinguish from the outset. Theory transfer in a strict sense presupposes - and assumes - isomorphism between the empirical phenomena which are to be described and explained, i.e. a 1 : 1 relationship between the elements, the properties, and the relationships of interdependence in two phenomenal fields. Two substantive theories with an identical formal structure can thus be considered as two different empirical applications of one underlying formal theory. Where the ontological basis for the transfer of theories (i.e. the basic isomorphism between the physical, organismic, and social worlds) is lacking, substantive borrowing is restricted, but can still take place for instance in the form of conceptual analo-

gies. Such analogies can be highly stimulating for theory development and research in the social sciences. Sometimes, however, a new terminology is only used to describe known phenomena in a different language, and this merely semantic innovation is falsely presented as a true gain in knowledge.

When formal models developed in some other discipline are applied to social phenomena, this can take two different forms. In the simpler case, the model, typically a mathematical equation or system of equations which generates a characteristic curve or distribution (change of a variable over time, change of a variable A as function of a variable B, or a spatial distribution), is used for descriptive purposes. Theory transfer here takes the form of fitting a curve generated by the model and descriptive of some physical or organic process, to data describing a social process. This would happen, for instance, if a formalized diffusion model from physics or biochemistry were used to describe the diffusion of an innovation in a human population. Such descriptive curve fitting, however, has no explanatory value. In particular, it is not legitimate to assume that the same kind of micro-processes generating a given curve or distribution in the physical world are at work also in social reality. As long as isomorphism at the level of microprocesses has not been proven, a descriptive model transfer at the level of process outcomes tells us nothing about the causal mechanisms generating it. To put it differently: isomorphism at the micro-level, or causal level, may not be simply inferred if curve-fitting works at the level of aggregate outcomes; such isomorphism must still be empirically established.

The social sciences are often said to be confronted with a series of difficulties which are connected with the nature of their objects and make the formulation of law-like statements with a high predictive power much more difficult than this is in the natural sciences. Prominent among these difficulties are the highly restricted applicability of the experimental method and the relatively narrow limits to the direct observation and quantification of social phenomena. Upon closer inspection, however, many of the assumed limitations to the use of natural science methods and models refer to differences in degree rather than being of a qualitative nature; they have to do



more with differences in analytical perspective than with different degrees of recalcitrance of the objects of cognition; or they do not hold for social sciences in general versus natural sciences in general, but only for specific social sciences, compared to specific natural sciences (e.g. for sociology in contrast to physics). Without being able to discuss these matters in detail at this point, it should be underlined that differences in perspectives, or in cognitive intent, and differences in the practical manipulability of the objects of investigation, decisive as they may be for the transfer of methods used in (some of) the natural sciences, are not the same as a basic, or essential, difference in the objects of cognition which would restrict the use of a methodology predicated upon the existence of causal regularities. We will come back to this issue in connection with the question of isomorphism in the final section.

## 2. Formalization and Mathematization in the Social Sciences

Formalization and mathematization are generally feasible only where we are dealing with relatively few variables and parameters. Where reality is complex, formalization requires simplification, i.e. leaving out many secondary variables which in the concrete event could in fact exert some influence. Such simplification is acceptable as long as it does not entail an inordinate loss in predictive power, or loss of congruence with reality. In the physical and, at least, partly also in the life sciences, it does seem possible to grasp the dynamics of real processes with relatively simple models; e.g. the behavior of gases can be described reasonably well by using only three interrelated variables (pressure, density, and temperature). In other areas, formalizations of the same degree of simplicity may be much more sensitive to the variation in neglected parameters, i.e. simplified models can be less robust. In sociology, the problem of simplification in formal modelling has been well recognized.<sup>4</sup>

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<sup>4</sup> See for instance Scheuch and Rüchemeyer (1972: 354 ff.) who emphasize that formal modelling requires a reduction of the factors that can be taken into account, emphasizing that this constitutes a

The formal and mathematical representation of social theories is a case of borrowing natural science methods only in a very general sense. There is a considerable variance in the degree of formalization and mathematization characteristic of different natural sciences, just as there is a difference in the emphasis put on the discovery of general rules, or natural laws. In these respects, paleontology, and possibly other life sciences as well, seem to differ as much from physics as sociology does. As a matter of principle, all disciplines can make use of logical and mathematical formalization to the extent that they are dealing with phenomena following or expressing some regularities. Where social scientists have turned to mathematical formalization, they may well have emulated modern economics rather than a natural science such as physics. Recently, however, some mathematically expressed physico-chemical theories have stimulated analogous forms of mathematical modelling in the social sciences.

In the construction of formal and mathematical models, one normally does not start with quantitative empirical data, but with theoretical assumptions about relations between variables: mathematical models *represent* social processes or systems of relations in a formal way. Mathematical models can be applied to real data in attempts to reproduce or extrapolate them. But as the prime purpose of mathematical models is the exact specification of relationships (in the simplest form: how A changes as a function of B), modelling proceeds often on the basis of assumed variable values, and the mathematical relationships are theoretically, rather than empirically derived. In solving mathematical models, the computational power of computers has been of great importance. But computers also made possible another form of formalization called computer simulation. The distinctive mark of simulation models is their use of *micro-level interactions* to generate macro effects (e.g. migration rates and patterns from the migratory decisions of a large number of simulated households).

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practical problem rather than a principal barrier to formalization in the social sciences. Warily they add, "Selbstverständlich bleiben auch praktische Begrenzungen echte Grenzen, deren Überschreitung nicht ohne schwere Gefahren möglich ist".

Mathematical formalization in the social sciences is not a very recent phenomenon. Already in the 60s, these efforts had sufficiently advanced to justify the publication of readers (e.g. Guetzkow 1962; McPhee 1963; Mayntz 1967) and a comprehensive treatment of the relevant methods (Coleman 1964). At this time, i.e. 20 to 30 years ago, mathematical models of diffusion processes were in use, systems of differential equations were analyzed for their equilibrium properties, graph theory was used to model structures of interpersonal relations, computer simulation had started, and game theory was used to model situations of strategic interdependence. In modelling exercises of the late 50s and early 60s, a certain fascination with stochastic processes, including Markov chains is visible, but there seems to have been no dominant influence of any specific natural science field on these modelling efforts, and in many articles no natural science analogy is drawn.

Throughout the past decades, formalization and mathematical modelling efforts have continued. There have been advances, often connected with the development of new mathematical methods, but no basic changes in these efforts. In the analysis of relational structures, for example, the simpler applications of graph theory have been replaced by the elaborate methods of network analysis which makes extensive use of matrix algebra (Ziegler 1984). Natural science analogies play no role in this field. Similarly, the social science applications of game theory make use of a branch of mathematics whose development may have been stimulated by theoretical considerations in economics, as the strategic choices made by rational actors are the basic notion in game theory.<sup>5</sup> The major trend in this field today is the effort to increase the descriptive applicability of game theory models to real social situations (see Ryll 1989).

In addition to relational networks and game situations, the dominant fields of application for mathematical models are still diffusion

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<sup>5</sup> Game theory provides a spectacular example of transfer from the social to the natural sciences, which is not discussed in this chapter; it has recently been applied with good success in evolutionary biology (see Maynard Smith 1982).



processes, migration and demography, and the generation and change of spatial structures. These are models which preferably use differential equations (i.e. calculus). There have been advances here, too, both in mathematical sophistication and in the effort to increase the fit of these models with empirical situations, and hence their descriptive and explanatory value for the analysis of real life phenomena. The formalized representation of diffusion processes may serve as an example. Through the work of Granovetter (1978, 1983), Markus (1987), and Marwell et al. (1988; see also Oliver et al. 1985), simple diffusion models, where the adoption rate is mainly a function of the assumed pattern of contact (random, in the simplest case) and the ratio between adopters and non-adopters, have been replaced by models in which the readiness to adopt is no longer a fixed parameter, but is assumed to vary across the population in question. It is furthermore taken into account that the individual likelihood to adopt varies in a discontinuous way with the proportion of previous adopters. This refinement has permitted to examine, for instance, critical mass phenomena in the diffusion of technical innovations, especially in the field of telecommunications (e.g. Allen 1988). The additional introduction of a "production function" relating effort to outcome has permitted the extension of diffusion models to mobilization processes, e.g. in political campaigning or in the collective production of some common good.

In all fields of formal modelling mentioned here, the production of macro-phenomena from behavior at the micro-level is the central issue. Such modelling is stimulated by and reinforces the recently intensified theoretical concern with spelling out the micro-macro link (Alexander et al. 1987). In game theory, the combination of strategic choices of interdependent players determines which of a set of alternative events will occur. In network analysis, a multiplicity of bilateral relations or group memberships generate different types of relational structures.<sup>6</sup> In other mathematical models it is the migrato-

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<sup>6</sup> In Coleman's exchange model, elements of network analysis are used to predict the outcome of decision processes, where this outcome is a function of the structure of differential control over the decision event (see Coleman 1986).

ry, reproductive, or imitative behavior of individuals which generates distributional structures at the population level. This last type of models, in particular, has a strong affinity to the school of methodological individualism represented by such authors as Boudon (1977) or Lindenberg (1977). Thus, intradisciplinary developments in social theory are probably the most important force sustaining formal modelling in the social sciences.

Recently, however, work in the natural sciences and in mathematics on the nonlinear dynamics of nonequilibrium systems has had a strong stimulus effect. This influence has been twofold. On the one hand, substantive theories of the behavior of natural nonequilibrium systems, especially the notions of self-organization and self-production (autopoiesis), have stimulated social science theorizing; this will be discussed in the next section. On the other hand, the mathematics used to represent nonlinear, discontinuous processes has influenced modelling efforts in the social sciences quite independently of any substantive analogies with natural processes or systems; to these we now turn.

Over the past decades, attention in the natural sciences has increasingly turned to phenomena which defy analysis in terms of the traditional physical world view with its assumptions of linearity and reversibility, i.e. to the behavior of systems remote from equilibrium and to discontinuous processes resulting from nonlinearity. After the recognition of the stochastic nature of many real processes, the attention paid to nonlinear processes means a further step away from the traditional mechanistic world view. Nonlinear systems display a number of behaviors which can be widely observed both in the natural and the social world. Their state variables can change discontinuously, producing phase jumps, i.e. sudden changes of state as in the phenomenon of ferro-magnetism or in superconductivity. In such discontinuous processes, threshold and critical mass phenomena often play a decisive role. A threshold phenomenon exists where a dependent variable initially does not react at all, or only very little, to continuous changes of an independent variable, but beyond a given point it reacts suddenly and strongly. The threshold may be defined by a critical mass, e.g. the number of particles of a specific kind that



must be present before a reaction sets in, but other kinds of threshold also exist. Discontinuous processes can also become completely irregular when a dynamic system enters a phase of turbulence, or chaotic behavior. Furthermore, the behavior characterized by nonlinear dynamics can display a specific kind of irreversibility, i.e. hysteresis (path dependency of phase jumps), and a specific kind of indeterminateness expressed in the term bifurcation, i.e. a point where a trajectory can proceed in different directions, the choice being determined by a minimal change in some parameter (which in reality is often neglected). The analysis of nonlinear dynamics has been enhanced by the development of new mathematical methods, as René Thom's catastrophe theory, and by the computational power of modern EDP,<sup>7</sup> which for instance made it possible to discover and formalize the phenomenon of deterministic chaos.

Efforts to model discontinuous processes in social systems have always been stimulated by the availability of analytical methods, quite apart from the influence of any substantive natural science theories. In the 50s and 60s, the development of mathematical graph theory and the mathematical theory of higher transition probabilities characteristic of Markov chains had stimulated social scientists to apply them to social phenomena (e.g. Harary 1959). Models of discontinuous processes have been developed particularly in work on social diffusion (Hummell/ Sodeur 1981; Mayntz 1988). Such processes may display sudden take-offs, they may escalate or come to an abrupt halt, or spiral downward as well as upward. While earlier continuous diffusion models were especially applied to the spreading of various kinds of innovations, discontinuous diffusion processes are typical of

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<sup>7</sup> This last point bears emphasis. In economic theory, for instance, the existence of nonlinear relationships has been recognized for long, but a selective interest in equilibrium conditions together with the prohibitive mathematical complexity of nonlinear systems has discouraged modelling attempts. Instead, de facto nonlinear economic relationships have mostly been linearized for mathematical treatment. A growing interest in nonequilibrium dynamics together with the greatly improved technical ability of dealing with more complex mathematical models has now led to changes in this situation (see Intriligator 1988).

collective and mass behavior, political campaigns, social movements, and the development of panics and riots.

An important effort in the mathematical analysis of discontinuities has been made by catastrophe theory, a branch of differential topology. Developed by René Thom (1972) and elaborated by Zeeman (1977), this theory was meant to provide a mathematical instrument for dealing with situations where the continuous variation of one or more parameters leads to sudden/discontinuous changes in the behavioral (or outcome) variable. More specifically, catastrophe theory is concerned with the classification of singularities of smooth functions. Within a given family of functions which differ in the values of the parameters, each function can be characterized by the singularities (minima, maxima, saddle points) it displays and can be categorized accordingly. For certain types of functions it has been observed that with incremental changes in the value of one or more parameters, the functions in a family "jump" from one category to another. They are therefore discontinuous in terms of a specific property (i.e. the number and characteristics of singularities). The change from one category to another is topologically represented.

Obviously, an application of catastrophe theory must have been very tempting in view of the observation that seemingly small disturbances will often cause a social or an economic system to enter into a state of instantaneous, radical change, or even to collapse. In fact, there have been attempts to develop social science applications immediately after the publication of the theory. However, it is obvious that a catastrophe in the mathematical sense just spelled out bears only a superficial resemblance to catastrophes in the colloquial sense - a sudden collapse of a system with severe consequences for people directly or indirectly affected. Above all, it would be erroneous to believe that the mathematical formalisms of Thom's catastrophe theory could directly help us to understand the causalities underlying social catastrophes. Before the mathematical theory can be applied, a number of assumptions must be made which are highly technical and difficult to translate into properties of real phenomena and their interrelationship. The utility of catastrophe theory hinges on the possibility to give a precise empirical meaning to the control and

behavioral variables and their interactions. In attempts to apply catastrophe theory to social or economic phenomena, this is often not possible, so that the model transfer remains at the level of a mere analogy which, moreover, is highly speculative as far as the underlying causal theory is concerned - a practice harshly criticized already by Sussman und Zahler (1978). Some authors have rightly stressed that catastrophe theory is nothing but a mathematical method of analyzing and representing a specific type of mathematical functions, and have admittedly used Thom's topological models in a merely illustrative way (e.g. Bühl 1984a). Others, however, have used the graphic (topological) representations which Thom uses to represent the singularity profiles of a family of mathematical functions with incrementally changing parameter values, by attributing directly some specific empirical meaning not only to the parametric dimension, but to all dimensions of the geometrical plane - in spite of the fact that the geometrical plane does not display changes in a state variable of the underlying function directly, but only changes in the categorical property of functions in a family. One example is Brian R. Flay (1978), who interprets Thom's geometrical models in terms of attitude change. What results from such attempts at application are metaphorical curve-fittings at the level of aggregate or outcome variables which do not explain why and at what point a threshold is passed and a phase transition occurs in reality.

This does not mean that catastrophe theory cannot be applied to economic and social phenomena, provided the system variables and parameters as well as the formal mode of their relationship in a potential function can be given strict empirical meaning. This in turn presupposes the availability of a qualitative model of the underlying empirical relationships linking control and behavioral variables, which can be transformed into a quantitative model. Thus, Zahn (1979) has tried to apply catastrophe theory to economic phenomena such as instabilities in financial markets or discontinuities in consumer behavior, but he emphasizes the difficulties of going, on the basis of existing empirical knowledge, beyond a vaguely illustrative use of the models. Casti (1982) succeeds in developing a formal model of changes in the growth rate of housing units in an area over time in a mathematical equation containing two (empirically interpreted)



parameters. He can show mathematically that for specific combinations of parameter values, the development of the growth rate, i.e. the mathematical function governing it will enter into a nonequilibrium state, either increasing suddenly or crashing. In a second application, Casti takes military action as the behavioral output variable; here functions which do not lead to an equilibrium state represent conflict erupting into war.

Deterministic chaos refers to a different type of discontinuity that can be mathematically analyzed (Schuster 1987). Chaos, i.e. irregular, unpatterned change in a state variable, has normally been interpreted as the consequence of uncontrolled or random external disturbances or as the consequence of a high degree of complexity (very large number of variables and parameters) in nonlinear systems. Essentially by using computers to solve the equations, it was discovered that the same kind of irregular behavior can also occur if the parameter values in a relatively simple nonlinear system fall into a specific range. These processes are deterministic insofar as no random external event is assumed to intervene; instead, there exists a well-defined set of equations generating the development over time.<sup>8</sup>

Albach (1988) has applied chaos theory to model the "death" of firms by insolvency or bankruptcy, where real turnover is assumed to depend on research intensity and the desired growth rate. He shows that for specific combinations of research rate and growth rate, the economic development of firms will result in either continuous growth or contraction, in various patterns of decreasing oscillations, and - for a small range in the combined values - in a completely chaotic movement that eventually passes the insolvency limit. With a

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<sup>8</sup> Baumol points out that the economic literature is replete with models generating some sort of cyclical behavior. "However, for the sake of analytic tractability the relationships were generally assumed ... to be linear. ... the assumption of linearity introduced to make cyclical models tractable analytically effectively blinded us to the possibility that chaotic behavior patterns would emerge" (Baumol 1987: 105). Only nonlinearity is capable of producing chaotic behavior. In the past few years, economic literature has already produced quite a crop of models capable of displaying chaotic properties.

continuous, incremental change of the decisive variables, the mathematical system presenting a firm will thus go through a pattern of movements as previously described, from continuous over periodic oscillations to chaotic, irregular movement. It may be of great importance to understand the nature of such deterministically chaotic systems; when chaos might spell system collapse or war, it is imperative to avoid driving the parameters into the range where deterministic chaos occurs (Großmann 1989).

It is important to note that in all of the applications discussed in this section, no learning takes place. True, in nonlinear models, the elements affect each other's behavior and are affected by the aggregate state which the system has reached in the previous time period, to which they themselves may have contributed. It is not assumed, however, that actors involved in a process about to move into a phase where the parameter values will lead to a loss of equilibrium or a chaotic movement, will deliberately control the parameters so as to avoid this happening. Nor is conscious action to control the parameters which govern systems development assumed in the analysis of processes of collective behavior found in diffusion models.

### 3. Self-Organization and Autopoiesis

In the development of modern science, classical thermodynamics introduced the notion of basically irreversible processes. The second law of thermodynamics, i.e. the entropy law maintains that all potential forms of energy are irreversibly transformed into thermal energy. The theory of dynamic nonequilibrium systems has in turn superseded classical thermodynamics. This second paradigmatic revolution started with many initially separate developments in different disciplines, including the mathematics of nonlinear dynamics discussed in the previous section. But while there the emphasis has been on phenomena of discontinuity, the instabilities resulting when a critical point is passed, the indeterminacy at bifurcation points, and the possibility of deterministic chaos, we shall now turn to a body of empirical and theoretical approaches which focus on the reverse



process, the phase transition from disorder to order through processes which have come to be called self-organization. Though not initially recognized by all independent contributors, theories of self-organization in the natural world can be considered, and have in fact become recognized as an integral part of an analysis of the dynamics of nonlinear, nonequilibrium systems. This is not only so because self-organization processes are mathematically formalized in terms of nonlinear dynamics. In addition, the phenomena investigated with the help of catastrophe theory and other methods of analyzing discontinuous processes, i.e. critical points, bifurcations, and phase transitions, turn out to be component phases also of processes of self-organization. Thus, self-organization is a special case of nonlinear dynamics.

The structuration processes analyzed in theories of self-organization are sometimes viewed in a highly inclusive manner. In particular self-reproduction (autopoiesis) is considered to be one form in which the self-organization of nonequilibrium systems can manifest itself.<sup>9</sup> Self-organization, in turn, is occasionally being subsumed under a general theory of evolution.<sup>10</sup> However, at such high levels of generality there is always the danger of a significant loss of information, and so we shall here treat self-organization, autopoiesis, and evolution separately.

As Krohn, Küppers & Paslack (1987) point out, several parallel, but independent research developments in the natural sciences have contributed to, and ultimately merged in the paradigm of self-organization. Heinz von Foerster was probably the first to formulate the new concept with precision. In his seminal article of 1960 (reprinted 1981), von Foerster already points to the two basic features of self-organizing natural systems, i.e. their operational closure and their dependence on energy input. Von Foerster developed his ideas in the

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<sup>9</sup> Jantsch (in Zeleny 1981a: 65) thus speaks of autopoiesis as a "central aspect of dissipative self-organization".

<sup>10</sup> E.g. by Laszlo (1986) who treats self-organization under the heading of "a general concept of evolution"; Jantsch (in Zeleny 1981a) quite similarly interprets evolutionary phenomena as sequences of self-organization at increasingly higher levels.

context of a critique of classical thermodynamics, especially of the second law of thermodynamics which maintains that in closed systems, entropy can only increase but will never decrease. Self-organizing systems apparently violate this law because they are able to go through a process of increasing order (in contrast to the increasing disorder postulated by the entropy law), and they do so quite remote from thermodynamic equilibrium.

The second major contribution to the self-organization paradigm comes from Ilya Prigogine, a chemist who had long been working on problems of irreversible processes in thermodynamics. Quite independently, he also tried to analyze apparently spontaneous ordering processes in diverse physical and chemical systems far from equilibrium which occur when some parameter passes a critical point, e.g. when one substance in a chemical system passes a given concentration (Prigogine/ Glansdorff 1971).

The third author to mention here is the physicist Hermann Haken, who discovered analogous ordering processes when he studied the laser phenomenon in the framework of quantum theory in the early 60s. He soon discovered that seemingly different physical, chemical, and biological systems behave in a similar manner, and coined the term synergetics to describe these processes. While Haken still emphasizes energy input as a condition of self-organization, the entropy concept recedes into the background in his work, "... the entropy concept ... is far too rough an instrument to cope with self-organizing structures. In general, in such structures entropy is changed only by a tiny amount" (Haken 1978: 12).

The conceptual framework of thermodynamics is left altogether in the work of Manfred Eigen who, since the late 60s, worked on processes of molecular self-organization or biogenesis. Eigen contributed the concept of hypercycle, an autocatalytic process composed of linked autocatalytic subprocesses (see Wuketits 1989: 64 ff.). Krohn et al. emphasize that the work of these various authors<sup>11</sup> was originally

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<sup>11</sup> Krohn et al. mention ecological studies as a fifth root of the paradigm of self-organization; we will come back to this facet of the

firmly located in quite diverse disciplinary contexts. Von Foerster came from cybernetics, Prigogine's theory of dissipative structures was a generalization of the formalism of irreversible thermodynamics to nonequilibrium processes, Haken came from quantum theory, and Eigen's theory of the hypercycle was embedded in his studies of the kinetics of fast reactions. However, the analogies soon became evident as these authors came to know each other's work, and both Prigogine and Haken set out to formulate a more comprehensive theory of self-organization. Already in 1978, Haken generalizes to physics, chemistry, and biology, and hints at a possible further extension to social phenomena. Similarly, Prigogine's book of 1980 is an attempt to generalize, though only in the context of the natural sciences. Recognition of the similarity of their mathematical formalisms led the authors to develop the analogy of their concepts and to spell out the underlying principle common to the various phenomena (Krohn et al. 1987: 454).

The main features of the self-organization paradigm are the following:

1. A self-organizing natural system is composed of a very large number of elements, which can be of the same kind or of a limited number of different kinds.
2. The system is in a state far from thermodynamic equilibrium; this has later been generalized to any nonequilibrium state.
3. The system receives an energy input, and consumes energy in the process of self-organization; energy input may be a necessary condition, but it is not identical with the order-producing mechanism.
4. The order, or structure, which emerges is a consequence of the interactions and interrelations among the elements of the system.<sup>12</sup>

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comprehensive paradigm in the next section.

<sup>12</sup> This corresponds to von Foerster's concept of a non-trivial system which he distinguishes from input-determined, trivial systems (von Foerster 1984).



5. The emergent order constitutes a new macro-quality of the system, i.e. it is more than a statistical representation of the distribution of elementary qualities.
6. The equations governing the process of self-organization are intrinsically nonlinear.<sup>13</sup> This implies that the major features of nonequilibrium systems discussed in the previous section are a part of the self-organization paradigm. Thus, passage to the new state of order is a phase transition taking place as a control parameter passes a critical point where fluctuations are no longer damped, but instead amplified. Furthermore, processes of self-organization pass through bifurcation points, where random events or minor fluctuations determine which of several alternative paths is taken.

The mechanisms of self-organization and the emergent macro-qualities of the systems differ appreciably from case to case. This can be illustrated by briefly looking at some of the best known examples used in the relevant literature. In the case of the so-called Bénard instability, when a liquid is heated a phase of irregular turbulence gives way at some point to a specific, circular pattern of fluid motion. The mechanism seems to be a mechanical one where the motion of some of the elements succeeds in dragging others along until a specific pattern of motion becomes dominant and is stabilized. Prigogine's "Brüsselator", in contrast, is a chemical cross- and autocatalytic system of several chemical reactions; if the concentration of a substance A exceeds a critical point, the concentrations of two other substances begin to oscillate regularly (which leads to a corresponding oscillation of colours). Here the core mechanism is a self-catalytic, chemical reaction. In the case of the laser, the core mechanism is

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<sup>13</sup> In the linear part of the thermodynamics of irreversible processes, the emergence of new structures is impossible. As stated by linear thermodynamics, a closed system tends towards the maximum dissipation of free energy and the highest level of entropy compatible with its boundary conditions. In contrast, systems far from equilibrium do not tend toward maximum entropy but may evolve towards new stationary states entirely different from the equilibrium state. The energy flow organizes the particles into structures.

located at the subatomic level, and the relevant macro quality is the generation of a specific type of lightbeam. In a famous example from biology, finally, a homogeneous mass of amoebae starts to form a mushroom-like structure (called fruiting bodies) which displays the ability of locomotion. Here the core mechanism consists in the production of a substance which the amoebae start to synthesize in case of a lack of nourishment; this substance induces, through chemical messages, the amoebae to aggregate in such a way that the colony starts a collective movement of which the individual organisms are unable.<sup>14</sup>

Mobile cell colonies, Bénard instabilities, and the laser may be interesting phenomena, but it is difficult to see how they can pass from being natural curiosities to being models of social processes and even of universal evolution. The relevance of such phenomena for a more comprehensive world view becomes visible as soon as the basic principles characterizing them are formulated in a more abstract fashion. It then becomes evident that the new paradigm of self-organization finds its place in a long intellectual history reaching back, as Krohn et al. (1987: 443) point out, as far as Aristotle: It is the old debate about the possibility of spontaneous order opposed to views of order as something imposed - a debate to which in modern times Kant and the 18th century social philosophers, but also Adam Smith and Darwin have contributed. The concept of self-organization does not only imply that stationary states can be attained far from a system's equilibrium, but also that such a process normally starts with the destabilization of a previous steady state. What the concept thus underlines is that instability, or the destabilization of a system, is the prerequisite for the occurrence of a new structural mode, a new order.

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<sup>14</sup> Other examples of self-organization processes in the biosphere involve the development of colour patterns shown by many animal hides (see Murray 1988) and the development of the cortical network in general and of binocular vision in particular (see Malsburg/ Singer 1988).



The theory of autopoiesis has increasingly come to be considered a further form in which self-organization of nonequilibrium systems can manifest itself. Maturana's and Varela's theory of autopoiesis is basically a neurophysiological theory of cognition, developed in opposition to simplified camera models of perception. Subsequently, autopoiesis has come to be illustrated preferably by reference to the biochemical processes in cell production and reproduction. Whereas self-organization, at least in the narrower, original sense, refers only to the internal generation of *structure*, autopoiesis assumes that in addition, the system also produces and reproduces its own elements. This is a characteristic feature of *living* systems; the chemical system of Prigogine's Brusselator, the physical system producing a laser beam, or the hydrodynamic system of the Bénard instability are unable to generate and regenerate the atoms and molecules which are their elements. For self-organization energy input, a triggering external force is needed, but the ordering process itself takes place in the interaction among the system's elements. In autopoiesis, this notion of operational closure is taken two steps further: Not only does the autopoietic process now go beyond the production of order and includes the production of the very elements of the system; operational closure now also includes the constitution of the system boundary by the self-organizing system itself.<sup>15</sup> The theory of autopoiesis is therefore a variant of a more general theory of operationally closed systems, i.e. it is a theory of operationally closed *living* systems.

Systems models which emphasize operational closure are no longer input-determined. True, cybernetic self-regulation models already went beyond the notion of a simple input/throughput/output system. But whereas in cybernetically self-regulated systems, control is achieved by the purposive manipulation of one (or at best a few) control variables which can compensate for the disturbing variation of other input factors, in an operationally closed system the endogenously

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<sup>15</sup> Zeleny (1981b: 6) defines an autopoietic system as a unity realized through a closed organization of production processes such that (1) this organization of the production process is regenerated through the interaction of its products, and (2) a topological boundary emerges in result.

produced within-put becomes increasingly more important for the system's output. In such a system, the output is increasingly a function of mechanisms entirely internal to the system (though energy-consuming). In autopoietic systems, finally, output production is often regarded as a mere by-product of internal processes revolving basically about reproduction.

The new paradigm of self-organizing and autopoietic systems quickly met with interest beyond the confines of the disciplines where it was originally developed. Not only was the close connection between the theories of dissipative structuring, synergetics, and the hypercycle recognized; there were also attempts to extend the generalized paradigm to social phenomena. Haken himself once described the generalizing procedure in these words: "In physics, chemistry, and biology, the self-organized formation of structures is observed ... a mathematical treatment is given to these self-organization processes. It turns out that they are governed by specific mathematical relations. ... an abstract formulation of these mathematical relations can be given which goes beyond the mathematical formulation based on formulas. We thus find general rules ... [which] ... may find applications to management theory and related fields" (Haken 1984: 33).<sup>16</sup> However, not all the natural scientists who contributed to the new paradigm were bent on extending it in this way. Thus, the two books edited by Zeleny in 1980 and 1981 do not only attest to the interest in the potential of the new paradigm of self-organization and autopoiesis, but also include critical voices like that of the general systems theorist Brian Gaines (chap. 9 in Zeleny 1981a) or of Varela himself who stated, "Frankly, I do not see how the definition of autopoiesis can be directly transposed to a variety of other situations, social systems for

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<sup>16</sup> Among those who have helped to generalize and popularize the concept of self-organization is Erich Jantsch (1982). According to his own testimony, he aims at "the formulation of a truly general dynamic system theory embracing the non-living as well as the living. The unifying perspective ... is provided by the paradigm of dissipative self-organization" (Jantsch in Zeleny 1981a: 65). At this level of generality the concept also becomes linked to theories of evolution.

instance" (in Zeleny 1981a: 38).<sup>17</sup> In fact, in the process of generalization necessary for an extended application of the new theories, elements specific to the context of discovery had to be increasingly neglected and their core concepts lost necessarily in specificity and precision. "Order" is then no longer a pattern of motion or of periodically oscillating colours, but any relatively stable arrangement of (social) elements. Abstracting from the context of thermodynamics, the meaning of nonequilibrium becomes similarly diffuse. In this way the very concept of self-organization becomes more vague as it is extended to phenomena not originally covered by it.

Over the past decade, the self-organization paradigm has been applied variously to social phenomena. Some of these applications, though guided by the substantive notion of self-organized macrostructures, make use of the mathematics developed to analyze nonlinear nonequilibrium systems, notably by Haken in his synergetics. Weidlich, a physicist closely connected with Haken, has for instance been interested in the formal analysis of migration (Weidlich/ Haag 1987; see also Weidlich/ Haag 1983); in fact, the development of spatial structures as studied by human geography seems particularly amenable to this kind of analysis. Gierer, who had previously studied biological pattern formation e.g. in cells, has modelled the development of economic inequalities "as a structural feature which is autonomously generated and thus related to general rules for interaction within the system" (Gierer 1981: 310). Erdmann & Fritsch (1989) have modelled processes of political opinion formation and of electoral behavior. Erdmann explicitly connects his work to Haken's general principle of synergetics which treats collective phenomena in multi-component systems whose elements produce emergent effects through their interactions. This "basic behavioral axiom" of synergetics obviously applies to many social phenomena, which can therefore be studied and modelled with the help of the mathematical theory of complex dynamic systems used by Haken for the formal description of certain natural phenomena (Erdmann 1986). As a last example of such applications one can refer to the work of Allen, Engelen and

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<sup>17</sup> See also Bühl (1984b) for a critique of the popularization tendencies of some natural scientists.



Sanglier (1986), who use nonlinear dynamics to model the spatial development of urban systems as the outcome of interdependent decisions concerning land use and transportation.

In many cases, rather than by formal modelling, the self-organization paradigm has been applied to social phenomena in the form of verbal analogies, or by looking for the *social* counterparts of the general principles underlying natural phenomena of self-organization. Sometimes, such applications have emphasized the *similarity* between the social and the natural phenomena involved. Laszlo, for instance, has tried to apply nonequilibrium thermodynamics à la Prigogine rather directly to technological change. Stating that human societies "... are [sic!] nonlinear and nonequilibrium systems, persisting in a flow of energy", Laszlo finds a specific directionality in history, according to which "... on the whole, capacities for the access, storage, and use of energy have increased, structural complexities have grown, and system entropy levels have correspondingly decreased" (Laszlo 1986: 281, 278). In a more metaphorical sense, Morgan (1986) applies the concept of autopoiesis to organizations, arguing that organizations are operationally closed systems which do not interact directly with their environment, which they therefore perceive in a highly selective manner. Hence, the environmental perceptions of organizations express more about their own mode of operation than about the quality of the environment. Application attempts such as these - and more examples could be given - hardly generate new insights. Whether the analogy is drawn directly or used in a wide, metaphoric sense, such attempts amount at best to a kind of verbal "curve-fitting".

The most ambitious social science attempts to make use of the self-organization (and autopoiesis) paradigm stand in the tradition of systems theory. Not surprisingly, the major applications along this line are today found in the German Federal Republic rather than in the United States. At an earlier time, American authors like Deutsch, Easton, and Parsons had been stimulated by cybernetic systems theory, the forerunner of the theory of self-organizing systems. But after Parsons, the focus of social science theorizing in the U.S. shifted away from systems theory, while in Germany with the work of Niklas Luhmann a theoretically very ambitious and highly sophisticated

ed new variant of sociological systems theory was developed (Luhmann 1984) and has influenced both the major theoretical debates and a whole generation of younger scholars. What authors like Luhmann, Teubner, Krohn & Küppers, and Stichweh focus on is not so much processes of spontaneous ordering, or self-organization in the narrower sense, but the self-production of social systems. That societies reproduce themselves through sexual reproduction and the socialization, or enculturation, of new-born members, is evident; in this sense, the autopoietic character of social systems is a well-known commonplace. In fact, Luhmann and the other authors just mentioned point to a different type of self-reproductive processes in applying the notion of autopoiesis to their objects of investigation (social systems, law, or science respectively).

Niklas Luhmann, for whom social systems are basically systems composed of specific types of communication, analyzes how communications structured by a - usually binary - code come to form operationally closed self-reproducing systems for which all other types of informational inputs are perturbations to be dealt with in terms of the given system's own way. Most recently, Luhmann has applied this general theoretical model to the economic system, whose essential dynamic consists in the continuous induction of payments by other payments (Luhmann 1988). In a money economy, payments can in fact be considered as communication by way of a specific medium. Also, payments do induce other payments. Of course, it can also happen that a payment is followed by a non-payment which, if generalized, means that the economic process breaks down. Hence, the continuous existence of the economic system depends on the self-reproductive capability of payments leading to other payments. To become economically relevant, other kinds of communicative acts or non-communicative events must be translated into the language of payments.

Gunther Teubner's application of the autopoiesis concept to law follows Luhmann and uses similar lines of reasoning (Luhmann 1981a, 1983; Teubner 1989). The elements of the legal system are once more a specific type of communication, i.e. judgments of legal/illegal, and the legal system is again seen as operationally closed and self-

reproductive. As *legal* acts, these communications are produced by the legal system (legal norms, procedures etc.). Teubner (1989), who in contrast to Luhmann insists that autopoiesis is a variable, i.e. that systems can be more or less autopoietic, argues that modern law *has become* autopoietic, i.e. an operationally closed system that produces all its components autonomously in a circular process (hypercycle). This implies that legal acts, as products of the legal system, are in turn able to reproduce or, more importantly, change the system (structure, processes) giving rise to legal acts. One consequence is that legal rules begin to be dissociated from social norms and values, so that the relation between society, or social needs, and legal rules is loosened. Where a legal system emerges as a second order autopoietic system over the first order autopoietic system, i.e. society, this is the effect of (blind) socio-cultural evolution taking place endogenously, within the legal system itself.

Yet another area to which the concept of self-organization has been applied is science. Krohn & Küppers (1989) argue that in the interactions taking place within research groups, rules for the generation of knowledge which can be accepted as scientific, as well as the scientific knowledge produced according to these rules, emerge. This implies that the boundary between science and non-science is constituted from within, i.e. through the science-producing process itself, as required by the notion of autopoiesis. Just as Luhmann and Teubner do not set out to explain the development of economic or legal institutions such as firms and corporations, banks and stock exchanges, courts, juries, and the bar association, Krohn & Küppers are not concerned with science as a *social* system, but they want to formulate a theory of *science* as a self-organizing system. However, they deviate from Luhmann's approach by not ascribing a self-generative power to the elements of science. Instead, it is a specific type of communicative interaction among researchers in which scientific statements are proposed, rejected, or provisionally stabilized. In other types of interactions across the boundary of the research group, which Krohn & Küppers call "sciencing" or "science-acting", researchers link the process of knowledge production to relevant sectors of the research group's environment by which they both structure this



environment and absorb its various effects into the production of knowledge and hence into science.

Rudolf Stichweh (1990) uses both the concept of self-organization and the concept of autopoiesis to analyze the development of modern science. A comparison with Krohn & Küppers illustrates that these concepts, if defined in a very abstract way, can easily be applied in rather different ways to the same object. Stichweh argues that the history of European science from the sixteenth to the second half of the eighteenth century can be interpreted as a process of self-organization of science because in this period, science consisted mainly in organizing received knowledge. In this context, self-organization means that elements of knowledge produced externally, i.e. outside of the science system, are subjected to an ordering process which results in an *internally* generated structure. From the second half of the eighteenth century on, a transformation from self-organization to autopoiesis takes place as the elements of science are increasingly produced within the science system, i.e. by experimentation and other forms of empirical research. "The novel aspect of an autopoietic system of science seems to be that the system starts to produce all its elements itself and, after having done this for some time, changes its identity: the self-production of new elements seems to become the essence of science" (Stichweh 1990).

These various applications of the paradigm of self-organization and autopoiesis have often met with harsh criticism.<sup>18</sup> However, even the critics sometimes find them stimulating. Thus, Wieland criticizes Luhmann's claim that payments have all properties of an autopoietic element, pointing out that it is human actors who make payments; nevertheless he thinks it useful to reformulate a number of problems in economic theory in terms of Luhmann's approach (Wieland 1988: 22 f.). Krohn & Küppers' thesis that what passes as "scientific knowl-

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<sup>18</sup> Even Peter Hejl, who uses the paradigm himself, joins the critics when he asks, "Autopoiesis - muß das sein?" (Hejl 1986). Autopoiesis theory itself and the claims which Maturana and Varela make for it is also looked at quite skeptically by many natural scientists.

edge" is produced in the interaction among researchers is a meaningful empirical statement that can be tested accordingly. Their analysis transcends the unfruitful debate about the internal or external determination of scientific knowledge in an integrated concept emphasizing the dual nature of scientific theories which on the one hand clearly reflect their social embeddedness (via the process of "sciencing"), while obeying at the same time specified criteria of argumentation and testing. The limit of the approach lies in its inability to explain equally well the morphogenesis of the *social* subsystem of science, which quite obviously does not take place only in a bottom-up process, let alone as a spontaneously generated emergent effect.

The analysis of the legal system in the framework of a theory of autopoiesis has superseded not only a simplified conception of law as a conditional program, or input/output system, but also the already more sophisticated notions of law as an adaptive system interacting with its social environment and of law as an instrument of political control. When the law now comes to be considered as an autopoietic system, the notions of input-control or environmental control are replaced by an emphasis on self-reference. Following the precept that autopoietic systems, while operationally closed, are yet energetically open (or resource dependent), the autopoietic legal system is not considered to be walled off against all external events, which rather serve to induce legal communication. Emphasis on the operational closure of the legal system highlights the necessary translation which external events must undergo before they can become objects of legal processing. It also reflects the very real autonomy of the normativity of legal communications better than any of the previous notions of the legal system. Emphasis on the self-referential character of the legal system may in some way appear to be even more realistic than the previous perception of law as an instrument of political intervention (Nocke 1986).

None of the authors discussed in this section makes an explicit claim of transferring a fully developed natural science theory to social phenomena. At least in his "Soziale Systeme" (1984), Luhmann employs a highly generalized systems theory, and this apparently obviates for him the need to discuss to what extent theory transfer is

possible. Teubner (1989) proceeds in roughly the same way. Krohn & Küppers (1989: 22) even point out explicitly that the paradigm of self-organization cannot simply be applied to new phenomena, but think it necessary to start by modelling each new field of application freshly. In doing so for the case of science, they aspire to empirical specificity and hence do not even claim generalization of their model of self-organization of science to other social systems.

In conclusion, it seems that social science applications of the paradigm of self-organization and autopoiesis are most stimulating and useful where they neither aspire to a detailed verbal curve-fitting, nor remain completely vague and metaphoric, but where a very abstract systems concept derived through generalization from the empirically specific work of a number of natural scientists is used as a guide for the formulation of analytical questions about specific social systems.

#### 4. Evolution and Ecology

In contrast to the very recent natural science theories discussed in the previous section, the theory of biological evolution is of venerable age and has been stimulating social thinking for generations. However, social scientists did not need biological theories to direct their attention to problems of social evolution. Thus, the evolutionary thinking of Herbert Spencer, who is even said to have coined the very term "evolution" (Wuketits 1989: 1), predates the publication of Darwin's book on the origin of the species. But Spencer felt strongly supported by Darwin and was undoubtedly influenced by him. In fact, the normative implications of the notion of natural selection with its assumption that the "survival of the fittest" optimizes adaptation, are too obvious to be bypassed by social and political theory. Especially in the early American sociology, where the influence of Spencer was particularly strong, a tradition of social Darwinism developed. Though in modified form, notions of natural selection have subsequently played a role in functionalist theories of social development from Malinowsky and Radcliffe-Brown over R.K. Merton to Talcott Parsons.



In sociological functionalism, however, no attempt at a conscious theory transfer was made, which also means that the question how biological and socio-cultural evolution might differ from each other was not explicitly raised. But this is exactly what has been happening more recently with relatively numerous attempts to formulate theories of socio-cultural, economic, and organizational evolution by making explicit reference to theories of biological evolution.

As has happened in the case of natural science theories of self-organization and autopoiesis, in the field of evolutionary theory, too, such attempts were partly initiated by natural scientists interested to test the explanatory power of their paradigm when applied to non-biological evolution. Such attempts have been made both with respect to cognitive evolution (e.g. Riedl 1981; Diettrich 1989) and with respect to cultural evolution (see particularly the work by Cavalli-Sforza/Feldman 1981; and Boyd/ Richerson 1985). Whereas socio-biologists, where they do not limit themselves to the study of the social behavior of animals, are interested in the biological foundations of human behavior,<sup>19</sup> Cavalli-Sforza & Feldman and Boyd & Richerson attempt to spell out what is specific about cultural evolution, using the model of biological evolution as a base line for comparison and modifying it explicitly where, instead of somatic traits, they attempt to explain changes in the distribution of cultural "traits" in a population.

Summarizing crudely, evolutionary biology attempts to reconstruct the "tree of speciation", to identify possible directional principles characterizing its development, and to find the causal mechanism(s) underlying the process. Whereas the bulk of biological research on evolution is probably devoted to the first question, the direction of evolu-

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<sup>19</sup> Edward O. Wilson, the outstanding representative of socio-biology, stresses that this discipline is interested in the *biological* foundations of the social behavior of all living organisms including man; he does not maintain that all of human behavior is genetically determined, but he is interested precisely in the role that biological evolution, i.e. natural selection, plays in social development (see Wilson 1975; Lumsden/ Wilson 1981). This is therefore not a case of theory *transfer*, but of paradigmatic extension and will thus not be discussed here.

tionary change towards "higher" or at least more complex forms of life has always been a fascinating issue for social theory. The core of recent transfer attempts, however, is the *causal* theory: the underlying mechanisms of a non-teleological, yet obviously directed developmental process. Within the framework of a causal, i.e. process rather than outcome-oriented analysis, biological evolution, which is a population level phenomenon, is based on a micro-level process of gene transmission and variation, phenotype formation, and selection (i.e. the differential survival of the phenotypes carrying different genes). The major causal elements in this scheme, random variation in genetic inheritance and environmental selection, are considered the core of the evolutionary paradigm (e.g. Elster 1983).

Cavalli-Sforza and Feldman, both geneticists, emphasize that the mechanisms of variation, transmission, and selection of cultural traits differ significantly from the corresponding biological mechanisms. Thus, cultural "mutations", or inventions, do not only happen randomly; often inventions are purposeful (though not necessarily adaptive). Cultural transmission is typically by teaching and imitation, and such teaching does not only take place between parents and children, but also horizontally and between non-relatives of different generations. The authors trace out the effect which different modes of cultural transmission have for the rates of change of trait frequencies in populations. The mechanism of cultural selection, finally, rests in the acceptance or rejection of what is being taught. There is, as the authors point out, no necessary correlation between cultural and natural selection, i.e. the cultural traits which are successfully transmitted do not necessarily promote Darwinian fitness (i.e. reproductive success) and can even run counter to it.

Following Cavalli-Sforza & Feldman, Boyd & Richerson develop a "dual inheritance model". Their discussion is explicitly phrased as a counterargument to a more radical socio-biologist position. Though mathematically their approach may be less sophisticated, they bring a wealth of empirical data to support it. The main forces of cultural evolution are analogues of random variation (i.e. learning errors), and of genetic drift, but in addition there is also guided variation (purposeful modification of behavior), and biased transmission, the process

which Cavalli-Sforza & Feldman called cultural selection. Like Cavalli-Sforza & Feldman, Boyd & Richerson also stress that "the behavior that enables an individual to maximize his chance to enculturate cultural offspring may not be the behavior that will maximize the transmission of genes to the next generation", i.e. natural selection and cultural selection can work at odds (Boyd/ Richerson 1985: 11). In fact, the question to what extent cultural inheritance could be genetically adaptive, is a central question for the authors in their debate with socio-biologist arguments.

Cavalli-Sforza & Feldman as well as Boyd & Richerson have explicitly taken their point of departure from a model of biological evolution and have developed their theories of cultural evolution as a formal analogy with the requisite modifications, tracing out the difference these differences make. In the sociology of organizations and, parallel to that, also in economics, similar attempts have been made in order to explain changes in the distribution of organizational traits in populations of firms and other (mostly economic) organizations.<sup>20</sup> Alchian (1950) has first tried to apply the principle of natural selection to the success and hence differential survival of firms, his basic argument being that in view of the uncertainty of the results of purposive action, profit maximization cannot serve to guide the choice of behavioral alternatives. Instead, there is trial and error behavior on the part of firms which is then rewarded or punished by competitive markets. Along the same lines, Nelson & Winter (1982) made a more ambitious attempt to explain economic change with the help of an evolutionary approach. The authors explicitly borrow basic ideas from biology, though they disavow any intention to pursue biological analogies for their own sake, and are ready to modify accepted biological theories in the interest of getting better economic theory (Nelson/ Winter 1982: 11). Central to their scheme is the idea of

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<sup>20</sup> Explicit reference to the explanatory model of evolutionary biology has also been made in other fields of social science investigation, e.g. in studies of the development of science (e.g. Hull 1988), or the origin of deviance and crime (Cohen/ Machalek 1988; Daly/ Wilson 1988). Since these, however, have remained relatively isolated attempts, they will not be discussed in more detail.



economic "natural selection". The market environment "provides a definition of success for business firms, and that definition is very closely related to their ability to survive and grow" (Nelson/ Winter 1982: 9). The behavior of firms is assumed to be subject to a kind of "organizational genetics": Business behavior is governed by routines of various kinds, including routines for changing routines. As firms with de facto successful routines survive and grow, their characteristics come to prevail in a growing portion of the industry. This selection mechanism is clearly analogous to the natural selection of genotypes with differential net reproduction rates in biological evolutionary theory (Nelson/ Winter 1982: 17).<sup>21</sup>

In the sociology of organizations, ideas very similar to those of Nelson & Winter were developed by Hannan & Freeman, and by Aldrich, from the late 70s onward (Hannan/ Freeman 1977; Freeman/ Hannan 1983; Aldrich 1979). In their seminal article of 1977,<sup>22</sup> Hannan & Freeman argue that in view of the high pressures making for organizational inertia, a model emphasizing competition and environmental selection can explain organizational change at the population level better than adaptationist approaches. Howard Aldrich, coming from a resource dependency perspective, also stressed environmental selection in his book of 1979, with strategic choice becoming a mechanism of variation. In Germany, these ideas were taken up by Alfred Kieser (Kieser 1985).<sup>23</sup> As in (traditional) biological theory, environmental selection is generally assumed to increase fitness - in spite of

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<sup>21</sup> The foregoing should not be interpreted as a comprehensive account of evolutionary thinking in economics. Aside from such analogizing attempts as those of Alchian, and Nelson & Winter, one also finds attempts to develop an evolutionary economic theory which forego borrowing from biological theory and instead try to construct evolutionary economics on the basis of methodological individualism (see Witt 1987).

<sup>22</sup> Sidney Winter had already published an article presenting his core idea in 1964; this is quoted by Hannan & Freeman.

<sup>23</sup> More recently, however, this author has criticized the approach (Kieser 1988).

a possible lack of purposively adaptive behavior on the part of individual organizations.

The decisive influence attributed to environmental selection in organizational (or economic) change at the population level has been challenged by authors such as Astley (see Astley 1985; Astley/Fombrun 1987) who point to the importance which the active search for niches which may open up in the process of technological development has for organizational development. In spelling out his critique, Astley bases his argument on concepts from community ecology which, in contrast to population ecology and population genetics, emphasizes not gradual adaptation (through environmental selection) but growing diversity of species (through environmental differentiation). While Astley is still applying ideas from biological theory, the whole approach has also been criticized more basically by Kaufman (1985) and Meyer & Zucker (1989). Though not explicitly formulated as a critique of biological analogies, these authors challenge the assumption that "fit" between organizations and environment - even if produced unintentionally, e.g. by market forces - determines survival. To the extent that their arguments are correct, these critics point to limits for the transfer of the more traditional biological models, even if appropriately modified.

Ideas from bio-ecology have not only been used in organization theory.<sup>24</sup> In fact, the ecosystem analogy played an important role in the rise of the famous Chicago school of urban sociology whose members studied certain aspects of American cities in the first quarter of the century. Amos Hawley, the main protagonist of a new sociological field he named human ecology, recalls, "Large-scale influxes of ethnically diverse populations, uncontrolled competition for space, rapid obsolescence of physical structures, and almost continuous redistribution of land uses presented a superficial picture of chaos. To

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<sup>24</sup> Ecology can be considered part of a more comprehensive evolutionary paradigm which does not focus on the changes in a species or the development of the tree of speciation, but emphasizes the level of the ecosystem, the community of organisms together with their habitat.

find order in the welter of change presented a challenge that could be met only in a macroscopic view of the phenomenon as a whole. A useful perspective was suggested by the then-current work of plant ecologists. ... Many of the features of the plant community seem to have analogies in the urban community" (Hawley 1986: 1 ff.). An ecological approach has also been used by Boulding (1981) to study the evolution of whole economic systems. Most recently, an ecological perspective has come to be applied to the relationship between modern industrial societies and the environment (see Dietz 1988 for a survey).

In contrast to such explicit attempts to make use of biological models, the macro-sociological theory of socio-cultural evolution, as briefly indicated above, has only been loosely related to biological thought of late. In the 20th century, the concept of evolution came to stand for a gradual, directed, and irreversible process of societal development. Contrasted to revolutionary change, it has in this form played a focal role in many theories of social change. In modern sociological systems theory,<sup>25</sup> social evolution is seen to operate in the process of social differentiation, but no explicit biological analogy is drawn. Characteristic of this approach is Talcott Parsons (1966), for whom social differentiation leads to the enhancement of the adaptive capacity of social systems, or "adaptive upgrading". This is a popularized notion of evolution as leading gradually to diversification and the development of ever higher forms of life.

More recently, however, sociological theories of societal development have come to make explicit reference to Darwinian concepts. One example is the macro-sociology of Giesen (1980) who, though using a basically familiar phase model of primitive, traditional, and modern societies, builds his analytical frame of reference on Darwin's notion

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<sup>25</sup> While sociological systems theory has been most receptive to evolutionary thought as well as to notions of self-organization and autopoiesis, authors of a different orientation such as, in Germany, Jürgen Habermas, have similarly been concerned with the principles of social evolution, though here the link to biological theory is even more tenuous (see Habermas 1976).



of natural selection and looks for the social counterpart of genes. Luhmann, who rejects Parsons' notion of evolution along with other components of the Parsonian paradigm, builds his own theory of societal development around the core concepts variation, selection, and retention (Luhmann 1981b; see also Luhmann 1975). For Luhmann, there is no inherent directedness in socio-cultural evolution; observed changes were possible, but not necessary. Luhmann does not attempt to develop his theory in analogy to a biological theory of evolution, but gives the mechanisms of variation, selection, and retention a specifically social meaning. Thus, the socio-cultural mechanism of variation is seen to rest in verbal communication, or language, while selection operates through the generalized media of communication, e.g. money and power. These media assure the (selective) spatial and temporal transmission of cultural patterns.

Lau (1981), who essentially follows Luhmann in this conception of variation and selection, links his analysis more closely to Darwinian evolution theory. By distinguishing between the basic elements, or core, of a theory, and its specifications which differ according to the field of empirical application, he reduces the theory of biological evolution to one general core assumption which he then proceeds to re-specify by interpreting the core terms sociologically. According to Lau, Darwinian theory basically maintains that the evolution of self-reproducing systems can be explained by the existence of structural variation which, due to selective environmental factors, lead to different reproductive chances (Lau 1981: 78 ff.). However, as does Luhmann, Lau construes selection as a mechanism of transmission which guarantees acceptance - a rather considerable reinterpretation of biological evolution theory. This relocation of selection which becomes *part* of the transmission process instead of happening in a subsequent phase, as is the case with plant and animal organisms, has also been a facet in the models of cultural evolution discussed earlier. It reflects the fact that human beings can indeed refuse what is being transmitted to them, so that selection does in fact operate here. A second selective process may, however, well take place at the group level, as organization sociologists and economists have argued, and this selection process may follow more closely the biological pattern of a differential survival of "carrier organisms" who differ in

their adaptation to a given environment. By paying attention both to possible similarities *and* differences between biological and socio-cultural evolution, a more differentiated understanding of the processes at work can thus be gained.

In modern theories of social development, the observation that succeeding higher levels of differentiation and complexity have in fact been evolving is often combined with the strict rejection of all teleological assumptions. This has been so not only in the case of Luhmann and his followers,<sup>26</sup> but holds similarly for Norbert Elias (1977) who does not use a systems theory approach. Where the biological theory of evolution has been associated with - implicit or explicit - teleological assumptions, macro-sociological theorists have consequently tended to reject biological analogies outright. A good example is Michael Schmid, who even tries to avoid the very concept of evolution in his theory of social change through structural selection, because the concept is presumably linked to the notion of a directed movement towards higher structural forms (Schmid 1982: 205).

Recent developments in biological theory should diminish the reservations of macro-sociologists with respect to the use of evolutionary models, especially since there exists a potential linkage of the evolutionary with the self-organization paradigm which is just beginning to be traced out. Thus, Boulding (in Zeleny 1981a: XI) refers to two 'time arrows', "... one is the famous second law of thermodynamics, that entropy increases and potential decays. The other time arrow is that of evolution, which segregates entropy and builds up increasingly complex structures of order, no doubt at the cost of creating more disorder elsewhere". Self-organization is here seen as the form in which evolution takes place - a view echoed by Laszlo, who similarly describes self-organization as the process underlying the evolution of complexity in the universe (Laszlo 1986: 277). However, in the self-

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<sup>26</sup> Even more than Luhmann, Helmut Willke (1982) emphasizes the de facto directedness of the process of development, which has finally lead to the emergence of self-regulating social systems capable of purposeful action.

organization and autopoiesis paradigm systems are neither directly determined by, nor simply adapting to their environment. Instead, perturbations which come from the environment, if sufficiently strong, trigger a process of (self-organized) restructuration, by which the system finds a new stationary state. In this perspective, morphogenesis is by jumps rather than gradual and incremental, it is driven by internal forces (the mode of operation characteristic of a system), and is essentially non-adaptive or at least non-optimizing. A link to evolutionary theory in biology can therefore exist only if the adaptationist stance which characterized this theory for a long time is modified - a development that has in fact gained momentum recently. Thus, there is at least partial disagreement about the gradual or discontinuous nature of change in biological development, the adaptiveness of biological development, and the relative importance of natural selection in the process. Evidently, a view of evolution proceeding in the form of relatively sudden jumps after periods of relative stability, rather than continuously and incrementally, has a stronger affinity with modern notions of nonlinear dynamics. In this view, mutations occurring at, or even defining bifurcation points in the process of development play a focal role. As a result, the shape of the evolutionary tree as a whole becomes *ex ante* as unpredictable as a stroke of lightning.<sup>27</sup> Similarly, a growing emphasis on alternative explanations for the observable traits of species aside from, or in addition to natural selection makes room for the recognition that dissipative structuring contributes to the development of form and function (e.g. Gould/ Lewontin 1979). Along these lines of thinking, a trained physicist has recently tried to cast evolution at all levels - the organic, the cognitive, and the social - in the framework of a paradigm of self-organization - which changes the perspective on organic evolution, too (Diettrich 1989). Thus, the increasingly visible

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<sup>27</sup> "Mit solchen fulgurierenden Systemen [wie dem elektrischen Blitz] können wir den Evolutionsstammbaum vergleichen, der von den Primaten zum *homo sapiens* führt. ... Ein solcher Stammbaum ist nicht nur eine bloße Analogie zum Blitz, er ist physikalisch dasselbe" (Cramer 1986: 1151).



interconnections between formal theories of nonlinear dynamics,<sup>28</sup> substantive theories of self-organization and autopoiesis, and theories of biological evolution may well motivate new transfer attempts with respect to the latter.

### 5. Theory Transfer: Motives, Forms, and Outcomes

It has been the purpose of the preceding sections to present in an orderly fashion the main avenues of recent social science borrowing from the natural sciences, not to reconstruct specific transfer processes and their underlying motives in detail. Nevertheless, a few observations about what drives the transfer process may be made. There is, first, the striking fact that such transfer as has taken place, is as much a result of "supply push", i.e. of proselytizing efforts by natural scientists, as of "demand pull". Again and again, natural scientists have attempted to generalize their area-specific insights to provide a key to the solution of much more comprehensive cognitive problems, if not a new way of interpreting the world. Thus, both Prigogine and Haken have claimed the transferability of their theoretical models to social systems and have even attempted to develop some applications themselves. In the bio-sciences, Maturana has similarly made transfer claims for the notion of autopoiesis, while others like the geneticists Cavalli-Sforza and Feldman have applied models of biological evolution to the process of cultural development. In fact, as Richerson remarks, biologists at least since Darwin "have shown a lively interest in the application of their theories to the special cases of humans" (Richerson 1979: 1).

What makes social scientists receptive to physico-chemical and biological theories is more than the observation of some striking, superficial similarities, e.g. the evident fact that social phenomena are often irreversible, path dependent, and non-linear, and that selection plays

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<sup>28</sup> For the connection between the mathematics of dynamic systems and biological theories of evolution see for instance Hofbauer/ Sigmund (1984).

a focal role in social processes. Nor are symbolic reasons decisive. Of course, it may seem attractive to express familiar social science insights in the language of the "hard" natural sciences. Undoubtedly attractive is also the normative-emotional colouring of some of the key terms, especially self-organization. In the context of the new social movements with which many sociologists spontaneously sympathize, the term self-organization refers to a bottom-up process that is opposed to all forms of top-down control, hierarchical authority, and bureaucracy. Superficially, this political concept of self-organization may appear analogous to dissipative structuring in the physical world, and Prigogine's and Haken's discoveries therefore seem to give support to a certain normative world view. In fact, however, the deliberate process of bottom-up group formation, to the extent that it is purposive collective action, is quite distinct from the decidedly unintentional nature of the ordering processes in natural self-organizing systems.<sup>29</sup> But this important difference is easily forgotten where a subjective normative conviction makes for the attractiveness of specific natural science models.

For many social scientists, however, it is indeed the unintentional nature of the processes which attracts them to the self-organization paradigm. The natural science notion of self-organization and autopoiesis holds the promise of providing a solution to long recognized theoretical problems in social theory. More specifically, the paradigm of self-organization means a distinct change in systems theory away from simple input/output notions of systems regulated by feedback control, i.e. classical cybernetics. A cybernetic view of society is essentially a theory of political regulation, of control through policy-making and policy implementation. The self-organization paradigm, in contrast, emphasizes what the cybernetic control theory and corresponding views of the political process have neglected, i.e. the *autonomous* forces of structuration which are operative in the various policy fields. A similar argument can be made for models of evolution applied to the explanation of economic change, or of changes in

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<sup>29</sup> In this connection it is important to distinguish between (spontaneous and uncoordinated) collective *behavior* and (concerted) collective *action*.

a "population" of organizations. In fact, all theories able to account for the spontaneous generation of structures have a clear affinity to the long-standing concern of social scientists with order as an emergent phenomenon - unplanned, as it may for instance develop through the operation of market forces.<sup>30</sup> Complementary, models of nonlinear dynamics leading not (directly) to new states of order, but (first) to various forms of discontinuity - phase transitions, turbulence, chaotic movement - might, if applicable to the social world, help to account for implementation deficits, policy failures, and ultimately the so-called crisis of non-governability. Such theoretical concerns receive a special significance by the recent instances of sudden destabilization of a number of apparently rather stable socialist regimes. More generally speaking, social scientists may be attracted by physical theories of nonlinear dynamics and phase jumps because in the situation of catastrophic dangers which world society seems to be facing, they are looking for suitable conceptual instruments to understand the mechanisms of radical discontinuities before it may be too late for learning to avoid them.<sup>31</sup>

Over and beyond such "applied" concerns, *all* of the natural science theories and mathematical models discussed in this paper have a common feature, which lies at the root of their general significance for social science applications: they all deal with the generation of macro events or macro patterns from micro processes. By virtue of

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<sup>30</sup> An early representative of this school of thought is Menger (1883). Well-known among sociologists is Hayek's formulation, "If social phenomena showed no order except in so far as they were consciously designed, there would be ... only problems of psychology. It is only in so far as some sort of order arises as a result of individual action but without being designed by any individual that a problem is raised which demands theoretical exploration" (Hayek 1955: 39). Hayek recognizes that his work "on the evolutionary formation of ... highly complex self-maintaining orders" has meanwhile become "a tributary of a growing stream", in which he explicitly includes synergetics, self-organization, and autopoiesis; see Hayek (1988: 9).

<sup>31</sup> This is explicitly argued for instance by John Casti (1982) and Kenyon De Greene (1981: 104).



their dealing with the micro-macro link in systems behavior, these models also contribute to a better understanding of the hierarchy problem. Hierarchy in this connection does not refer to vertical control relationships, but to a succession of different levels where the phenomena at each higher level have properties that cannot be derived by summation from the properties of the lower level phenomena. In this sense, the solar system, a human being, and even the human brain - where the relationship between psychic functions, neurophysiological processes, and physico-chemical processes at the sub-cellular level is still unsolved - are hierarchical phenomena. The same can be said of social systems, where a corresponding distinction is made between micro and macro phenomena. To the extent that the natural science models can be applied to social reality, they might therefore help to clarify the micro-macro link, i.e. what is probably the most crucial general problem in present social theorizing.

This special theoretical relevance may have been most evident in the case of the self-organization paradigm. But as pointed out earlier, mathematical models of nonlinear dynamics, whether they are producing phase jumps and other kinds of discontinuity or generating new structures, e.g. of political party adherence or residential segregation, similarly deal with the emergence or change of macro qualities from the uncoordinated (though interdependent) micro behavior of the system elements. The same is true in models of evolutionary change, where micro-level processes of reproduction and differential survival generate either patterned change or pattern maintenance at the population level.

That a theory of self-organization should be able to contribute to a specification of the famous micro-macro link is explicitly recognized by its natural science proponents. The point they all emphasize is that self-organization produces qualities at the macro level of the systems considered which cannot be derived from, or explained by, reference to the measurable properties of the elements. With reference to ferromagnetism and the laser, Haken for instance states, "Thus the order on the microscopic level is a cause of a new feature of the material on the macroscopic level" (Haken 1978: 3). In the case of iron, it is the quality of magnetism, in the case of the laser, a light

beam of particular intensity that is generated. Similarly, in the case of the Bénard instability, the macro quality is a pattern of fluid motion which obviously cannot be derived directly from the qualities of the  $H_2O$  molecules. Since, in Haken's words, "to describe collective behavior we need entirely new concepts compared to the microscopic description" (Haken 1978: 13), he introduces the term 'order parameters' to refer to such macro-features. An order parameter represents a macroscopic property emergent from interactions at the microscopic level.<sup>32</sup> Of course, the properties of the elements *are* important because they imply specific capacities for influencing each other and being influenced, but it is their *interaction* which produces the new structure. It is evident that these formulations can also be applied to the relationship between micro behavior (individual behavior) and macro properties of social systems. The promise to gain a better understanding of emergent effects in social systems resulting from the behavior and interactions of the system members is probably the main reason for the attractiveness of the self-organization paradigm to social scientists, and it plays a focal role also in the transfer of mathematical models of nonlinear processes, and of evolutionary theory.

In the beginning of this paper several different forms of borrowing from the natural sciences have been distinguished: the transfer of methods, of concepts, and of complete theories. Theory transfer in the strict sense practically does not take place. Aside from the borrowing of mathematical methods and models, the transfer efforts we have reviewed are basically of two kinds: they either remain largely at the level of verbal analogies, or they are cases of an indirect, or mediated theory transfer that proceeds through the generalization and a successive respecification of natural science theories. Both may appear as a kind of conceptual borrowing; that is, a transfer of concepts can take place in both guises, which it is important to keep apart.

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<sup>32</sup> De Greene (1981: 105); De Greene emphasizes this point strongly: Mere growth corresponds to deterministic factors, non-linear processes of self-organization lead to the emergence of new properties in a transition to higher levels of organization.

Examples of a merely metaphorical use of natural science theories, often presented with the claim of being a direct theory transfer, can be found in all of the substantive areas covered here. A considerable part of what might pass as theory transfer is thus nothing but the translation of already well-established parts of a social science theory into the conceptual language used in a natural science theory. Terms like equilibrium, self-organization, feedback, bifurcation, critical mass, phase transition, and operational closure can be applied, in a general descriptive sense, to a large number of social phenomena, though the similarity with the natural phenomena for which they were coined remains quite superficial. The result is not theory transfer, but a mere semantic innovation which adds nothing to our substantive knowledge. Of course, suggestive if superficial similarities with natural phenomena can stimulate conceptual development and theory building in the social sciences; but this should then no longer be presented as theory transfer.

It is probably not surprising that a merely metaphorical use of natural science concepts to describe social phenomena is often made by authors who are themselves natural scientists. For example, Haken himself (1984) has drawn suggestive verbal analogies between synergetics and organizational processes, analogies which presuppose a certain familiarity with organizational phenomena but do not add anything to our knowledge about them. But there is at least an equal number of social scientists who, having familiarized themselves with the corresponding natural science theories, engage in the same kind of effort with the same result. Thus Michelitsch (1987) describes basically well-known economic processes in the terminology of Prigogine and Haken. Another example referred to above was Morgan (1986), who applied the terminology of autopoiesis to organizations. In these and most similar cases, the "applied" statements are not "wrong"; they simply do not carry new information, which means that nothing but a translation, a semantic innovation has taken place.

To present a merely metaphorical use of natural science concepts as genuine theory transfer is relatively rare among social scientists who have themselves made substantive contributions to social theory. Instead we find here - if substantive borrowing from the natural



sciences takes place at all - what has just been referred to as mediated theory transfer. Such transfer implies the sociological respecification of a previously generalized version (possibly, but not necessarily in a mathematical form) of an empirical, i.e. field-specific natural science theory.<sup>33</sup> In fact, without such generalization of the original theory, social scientists might rarely be tempted to borrow from the natural sciences, which underlines the importance of generalization (and popularization) for theory transfer. In the process of generalization, which always implies abstraction, important parts of the original theories are lost. In theories of self-organization, this is typically the notion that these processes take place far from *thermodynamic* equilibrium. The same holds for the energy input (in a literal, physical sense) which dissipative structuring presupposes.<sup>34</sup> Similarly, there is no possibility to transfer the mechanisms which produce the higher level order phenomena in physical and chemical systems, such as chemical auto- and cross-catalysis, to social systems in any but a metaphorical sense. If, however, the paradigm of self-organization is reduced to a few basic principles, such as the coexistence of operational closure and sensitivity to external perturbations, and the emergence of quasi-stationary states through internal dynamic mechanisms of a nonlinear kind, these notions, when specified for social systems, can prove quite fruitful. Similarly, in evolutionary theory, one has to abstract from the genetic mechanisms underlying the biological inheritance of traits, to generalize "inheritance" to the notion of trait transmission, and respecify what transmission means in the social world. Such respecification requires more original theory building than simple application in the sense of using a template. What happens in such cases of transfer is that the verbal abstraction

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<sup>33</sup> Druwe (1988) calls the generalized version of a field-specific theory "model".

<sup>34</sup> Of course, societies might be called systems remote from thermodynamic equilibrium, if we include in the concept society the organisms of its members, processes of resource utilization and the production of artefacts, but the fact of being remote from *thermodynamic* equilibrium is not very informative with respect to what interests us about a society. Again, social systems consume energy, but it is not this fact per se but rather its technological and social consequences which interest us.

of theory A is used to generate new explanatory hypotheses in constructing a theory B. The generalized version of theory A thus serves as research heuristics.

The process of generalization and respecification has been described very well by Druwe (1988), though it often remains implicit in the writing of social scientists.<sup>35</sup> This holds particularly for applications of the self-organization paradigm. One of the few *explicit* attempts to move from Maturana's biological theory of cognition to a general theory of self-referential systems has been undertaken by Hejl who, though he does not get very far in developing it, claims that such a theory might provide a new theoretical foundation for the social sciences (Hejl 1982: esp. 191).<sup>36</sup> Luhmann, on the other hand, starts immediately by specifying the *sociological* meaning of an already generalized analytical paradigm. The (relative) openness characteristic of self-organizing and autopoietic systems for instance, is respecified by Luhmann to refer to informational inputs, or observations. Krohn & Küppers (1989: 127) even emphasize that it is this *informational* openness characteristic of *social* systems which lies at the base of their specific dynamics, if compared to that of biological systems. A similarly important respecification takes place with respect to the notion of autopoiesis, which Luhmann, as it were, de-materializes. In the field of biological evolution theory, most of the fruitful applications to social processes of change have likewise started from a very general notion of variation and selection and have given them a specifically social or cultural meaning. Thus, in the judgment of John Elster (1983: 147), Nelson and Winter, who applied the biological theory of evolution to explain economic change, are "very sensitive to the many disanalogies between the two theories"; the "broad analogy results in the use, in both theories, of stochastic variation and subsequent deterministic selection". This general principle of stochastic variation and deterministic selection, or "blind-variation-and-selective-

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<sup>35</sup> An exception is Stichweh (1987), see page 447.

<sup>36</sup> A similar claim has earlier been made for general systems theory, which is a good example of the *generalization* process referred to here.

retention", as Campbell puts it, is the abstract core of neo-Darwinian evolutionary theory (Campbell 1975: 1105).

Thus, both self-organization and evolutionary theory were first reduced to a few relatively simple, basic notions before being transferred to a different field. The potential fruitfulness of such transfer efforts rests in the explicit respecification - and hence authentic theory building - which they can involve. In the case of sociological systems theory, the notions of self-referentiality, operational closure etc. have led to a new perspective on societies and social sub-systems which in many respects can be considered to be not only more congruent with actual experience and observation, but also more satisfactory in an explanatory way. In the case of Nelson & Winter, replacing the classical economic notion of a maximizing rationality by the notion of "search" as a specification of what "variation" can mean if applied to the strategic behavior of firms, and replacing the classical notion of equilibrium by the notion of selection, has produced a very different perspective on economic phenomena. What we do in such cases is not to use a natural science theory to explain social phenomena, but the natural science theory stimulates a new way of viewing the social phenomena which, guided by some rather abstract notions, triggers a process of social science theory building. Strictly speaking, the potentially most productive mode of borrowing is therefore one where transfer in a direct way does not take place at all.

Where a generalized theory (or model) is applied to a new field, an implicit isomorphism hypothesis may be entertained, but to test it is not the goal. The central issue is, rather, the specific differences existing between the original and the new field of application. In contrast, theory transfer in the strict sense, i.e. the application of a theory with proven descriptive and explanatory validity in a phenomenal field A to a different field B, presupposes a basic isomorphism of the two fields, i.e. identity or close similarity of their structure - elements, forces, and relationships. Genuine theory transfer attempts therefore require a careful consideration of the isomorphism issue. Isomorphism can never be postulated a priori, but is subject to empirical proof, which means that a statement of isomorphism can never precede efforts of theory transfer. These conditions of theory



transfer in the strict sense are difficult to fulfill, and even where isomorphism exists, it is difficult to recognize unless the theories involved happen to be formalized in an analogous way, e.g. using the same kind of mathematics. The main reason for the prevalence of a rather indirect mode of theory transfer via general paradigms that need respecification before they can be empirically applied is therefore obviously linked to the limited isomorphism between the phenomenal fields of the natural and the social sciences.

An extended debate of this ontological issue cannot be the purpose of this survey, but a few general remarks should nevertheless be made. Offhand one would expect that isomorphism is particularly limited with respect to the physico-chemical sciences, while biological theories might appear closer to sociological applicability. Social systems may be nonequilibrium systems characterized by nonlinear dynamics, but the basic premise of physical and chemical theories, i.e. the invariant nature of their elements in time and space (e.g. a  $H_2O$  molecule is the same everywhere at any time) does not hold in the social world. Hence, the recurrent nature of the phenomena to be explained that is characteristic of the physical sciences can also not be assumed in social reality.<sup>37</sup> In the life sciences, the postulate of elementary invariance may be less valid than in the physical sciences, but there is still a significant difference to sociology because in comparison with other organisms, the behavior of human beings is genetically highly underdetermined. Instead, immaterial factors and learning play important roles in determining human behavior.<sup>38</sup>

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<sup>37</sup> This is recognized by thoughtful natural scientists; see for instance Markl (1989: especially 133).

<sup>38</sup> The issue of elementary invariance is not the only one to be considered in a more extensive discussion of isomorphism between social, organic, and physico-chemical systems. Differences in complexity, not only in degree but also in kind, may also be an important restriction especially for the transfer of formally expressed natural science theories, but for reasons of space, this issue will not be taken up here.

Compared to the animal world, the most important characteristic of humans is not even the - significant - difference in individual learning capacity and hence in the plasticity or malleability (and therefore the potential variance) of individual behavior, but the fact that change at the level of the population which implies learning or adaptation is essentially of a non-genetic nature. In the animal world, "learning" at the population or systems level takes place through variation and natural selection. But while animals can transmit little of what they have learnt in the course of their life time, such a direct transmission of skills, customs, norms, values and knowledge is characteristic of human society. Human learning, moreover, is not only cognitively mediated, it is also an essentially reflexive process involving self-observation, self-evaluation, and deliberate self-change. This reflexive learning process lies at the core of the low degree of temporal invariance of the human elements in social theories. Only in the social world are the elements able to change themselves willfully, can a system change purposively the values of its own parameters.

Wherever such learning and self-change takes place, the relatively simple models of collective behavior leading to changes in the order parameters at the systems level, models which assume a spatial and temporal invariance of the behavioral tendencies of the human elements can no longer be applied. This holds not only for (physical) models of self-organization, but also for the biological model of evolutionary change through variation and selection. If the differential survival rates of behavioral forms, or socio-cultural traits, are radically decoupled from the physical survival and reproductive performance of specific organisms, a rather fundamental reinterpretation of what selection means in the social world is obviously necessary. Only where we do have a relatively unproblematic survival criterion, as in the case of firms going bankrupt and being dissolved, can a properly reinterpreted evolutionary model be fruitfully applied. But there are many cases of social change - particular politically guided, planned social change - to which an evolutionary model cannot meaningfully be applied. Whereas in the case of the self-organization paradigm, isomorphism is limited by the individual capacity for reflection, learning, and wilful self-change, with respect to the paradigm of

biological evolution isomorphism is limited by the human capacity to change social structures and institutions deliberately.

But limitation is not total exclusion. In the beginning of this paper it was argued that apparently basic, qualitative differences between the natural and the social sciences often turn out to be, on closer inspection, differences in degree. Thus, historically unique phenomena also exist in the natural world, while on the other hand, the premise of invariance of the elements is not totally unrealistic for the non-physical (i.e. the social and the life) sciences. In the life sciences, the postulate of invariance may be generally less valid than in the physical sciences, but its validity is relatively higher for cells than for whole organisms. In the physical world, too, the assumption that all elements of a specific type behave in the same way holds for atoms and molecules more than it does for grains of sand and mountains - though here the behavioral differences could still be accounted for in terms of relatively few and simple parameters such as size/weight, form/aerodynamic friction potential, etc. Apparently, the invariance of elements is at least partly a function of the level at which elements are defined: it holds more for silicon molecules than for grains of sand, and more for the latter than for sand dunes.

In the social sciences, too, phenomena can be found where the assumption of elementary invariance holds at least approximately. This is true particularly where we deal with the collective behavior of relatively large human populations limited in time and space. In such situations, it may still be a simplification, but it is not impossible to describe the behavior of the individuals in terms of relatively simple empirical regularities which remain stable for the period under consideration. Such stability does not preclude mutual influence, though it would exclude learning which leads to a qualitative change of the behavioral rules. Phenomena of collective behavior also fulfill a second prerequisite for the transfer of the natural science paradigm of self-organization. Theories of self-organization in the natural world do not only imply invariant elements (though this is not what distinguishes them from linear and equilibrium systems, and is therefore rarely mentioned explicitly); self-organization also presupposes that the systems are composed of *numerous* elements which are either of



the same kind or of a limited number of different kinds (e.g. molecules). Both of these conditions of natural self-organization processes are met where we deal with human populations limited in time and space, and with phenomena of collective behavior. Where the effect of collective behavior (not collective action!) is more than the sum of independent individual acts, but involves some form of interaction and interdependence, collective behavior can therefore resemble the process of self-organization which produces change in a (non-aggregative) macro variable (or order parameter). It is not surprising, therefore, that the mathematics typical of theories of self-organization, nonlinear dynamic differential equations, is used particularly to describe emergent effects in social systems which result from a specific kind of interdependence among the actions of the individuals in a (large) population. The assumption of elementary invariance is neither generally true nor generally false in the social world; there are certain social phenomena where they hold approximately, and which therefore lend themselves to an analysis using the conceptual framework and also the formal methods of a generalized theory of natural self-organization. In fact, as the survey of recent mathematical modelling exercises has shown, these efforts concentrate exactly on such empirical cases.

A similar argument could be made for the paradigm of biological evolution, which appears most applicable where we deal with populations of social units whose relevant properties are relatively stable, i.e. tightly connected with the "carrier organism", and who are subject to environmental survival pressures which they might escape by moving away from the territory, but are unable to affect at will. There are indeed situations where these assumptions do not seem unrealistic, as in the case of a population of firms in a perfect, i.e. atomistic and strongly competitive market. The limits to a fruitful transfer of the paradigms from the natural sciences which at present appear to be most attractive, i.e. theories of nonlinear dynamics, of natural processes of self-organization, and of biological evolution, are drawn where the specifics of social reality - the influence of symbolic factors on behavior, the human capacities for conscious learning and purposive intervention into spontaneous processes - play major roles.

Of course it might be argued that the distinctively social (or human) features emphasized here might be incorporated into social science theories which follow the corresponding natural science paradigms. Thus, regular forms of value change, learning, or other forms of elementary change could be integrated into a model of collective behavior. Similarly, "dual inheritance" models have attempted to account for social transmission processes in the context of formal theories modelled after biological evolution. But a forced extension of the parallelism between natural and social phenomena does not increase our substantive understanding of social events and processes. For the building of social theories proper, it is more fruitful to start with a precise description of the *differentia specifica* of social phenomena. This will then point the way to salient issues in social theory building. Thus, reference to the indeterminateness of observable human behavior directs attention to those social institutions which put in fact relatively narrow limits on the variability and hence unpredictability of social behavior - a line of investigation chosen by Max Weber, who looked for the source of regularity in social behavior in custom, norms, and structurally given means-end relations.

What then can be the overall importance of borrowing from the natural sciences for the social sciences? Considering only the potentially positive effects, it could well be argued that the most salient advances in social science theorizing, i.e. the increasingly sophisticated treatment of the so-called micro-macro link, are quite unrelated to such external inputs (or stimuli), being instead a result of the debate between different approaches within sociology. In the case of the micro-macro problem, this has been the debate between action theory (or agency approaches) on the one hand, and systems approaches on the other. None of the substantive transfers from the natural sciences have led to major discoveries or paradigm changes in the social sciences. In fact, a paradigm change in the natural sciences has often been the precondition for a growing interest of social scientists - most notably so in the case of nonlinear dynamics. Put differently, social scientists have been receptive to natural science theories when they thought thus to find help in solving their own, already well structured problems, but they have generally not been impelled to ask completely new questions. The most fruitful effect has probably been

the stimulation of genuine social theory building by the application of highly generalized conceptual or explanatory paradigms *derived* from natural science theories. Often, transfer attempts have also helped to clarify important theoretical assumptions. The use of mathematical models in particular, though of limited applicability, because in a system of nonlinear equations it is difficult to deal with many variables, can help social scientists to spell out assumed interrelationships more precisely, and to trace the effects of variable constellations which are not easily perceived where theory remains discursive and qualitative. Used largely as an instrument for heuristic purposes, the effects of theory transfer from the natural sciences - to the extent that it has actually taken place - have therefore been mainly salutary, but not of revolutionary importance for the social sciences.



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