4. Theorizing the Complex

As mentioned in Chapter 3, the ongoing debate about the evaluation of HIV prevention not only encompasses practical and conceptual considerations, but also epistemological issues. It can be argued that the staunchest proponents of randomized clinical trials are working within the dominant scientific paradigm, based on an established tradition of analytical science. The concept of triangulation provides a methodological challenge to experimentalists, but without offering a systematic option. Thus, the debate on evaluation in this field has stagnated. In this chapter complexity theory will be presented as a cohesive alternative to the dominant scientific paradigm which integrates several developments within public health in recent years.

4.1 The Dominant Scientific Paradigm

> *We come from a past of conflicting certitudes, be they related to science, ethics or social systems, to a present of considerable questioning, including questioning about the intrinsic possibility of certainties. Perhaps we are witnessing the end of a type of rationality that is no longer appropriate to our time. The accent we call for is one placed on the complex, the temporal and the unstable, which corresponds today to a transdisciplinary movement gaining in vigor. This is not by any means a call to abandon the concept of substantive rationality. [. . .] The project which remains central to both the students of human social life and to the natural scientists is the intelligibility of the world. (Gulbenkian Commission 1996, p. 79; as quoted in Byrne 1998, p. 159)*

The history of Western thought has been marked by profound philosophical and methodological changes since humankind first began reflecting systematically about the world and our place within it. We in the modern period have tended to think of science as progressing along a smooth trajectory from an age of collective ignorance to a technological mastery of the environment. However, the current historical view calls into question both the implicit linearity and gradualism of this statement as well as the meaning of the word "progress" itself. As Thomas S. Kuhn (1970) observed, the paradigms governing scientific inquiry do not develop slowly through the accumulation of knowledge, but rather through "revolutions," each characterized by a new view of the world which alters both the focus of science and its epistemological assumptions. And as the problems created by technology have become increasingly apparent—including environmental catastrophes and unprecedented mass destruction through war—the notion that human knowledge always makes things better steadily lost credibility over the last century.

The current uncertainty and doubt, as aptly described in the above quotation, can best be understood when examining the characteristics which have come to dominate scientific theory and practice in Western culture and contrasting these characteristics with alternative approaches.

Several accounts have traced the rise of empiricism during the Renaissance and Enlightenment periods leading to the development of the scientific method and its application to all fields of inquiry. In general, the empiricist position holds that there is a world "out there" apart from the subject which functions according to set rules and which can be studied systematically through experimentation. This separation of subject and object and the focus on observation as the source of knowledge stand in sharp contrast to the earlier classical tradition which viewed the rational thought process itself as the source of truth. Empiricism allowed for a separation of systematic inquiry from particular political and ideological restraints imposed by religion and various forms of philosophical formalism. It is the empirical approach which is the basis of the current dominant scientific paradigm.

The development of the dominant paradigm has a long history which has been influenced by several theorists and practitioners from various periods of time, figures as diverse as René Descartes, Pierre Laplace, Auguste Comte, Emile Durkheim, and Karl Popper. As is typical for a dominant or generally accepted way of thinking, the most widely practiced approach in the natural and social sciences does not have a generally recognized name; it is simply taken for granted by many as being the way science is done. Usually the labels come from detractors of this approach, these labels varying according to the discipline and ideological perspective of the author, for example: *Newtonian* or *classical* physics; *Cartesian* approaches; *positivism, post-positivism,* or *logical positivism*; the *accepted* or *conventional view*; *logical empiricism*; *naturalism*; the *covering law model*; *behaviorism*; the *biomedical model*, and *determinism* or *scientific determinism*.[6] The question of interest here is, regardless of the label, what are the features of the dominant scientific paradigm?

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[6] It can be argued that certain of these labels do not apply generally to the dominant scientific paradigm, but rather to particular expressions of the paradigm in specific fields, for example, the *biomedi-*

When presenting the main features of a paradigm we are necessarily limited to an ideal typical description focusing on common themes rather than specific differences. The what and how of science have always been a topic of debate; even within "mainline" or "accepted" approaches there is a great diversity in regard to epistemology and methodology. It is, nonetheless, useful to attempt a description of the main features of the dominant paradigm in order to expose assumptions which are seldom discussed within the research literature. These assumptions will be used later to distinguish the dominant paradigm from other approaches, including complexity theory.

4.1.1 Characteristics of the Dominant Paradigm

The main tenets underlying the dominant scientific paradigm can be summarized as follows (cf. Giddens 1978; Phillips 1971; Harre 1972; Suppe 1977; Neuman 1997; Byrne 1998; Kellert 1993; Masterpasqua & Perna 1997; Kießling 1998; Kiel & Elliott 1996):

The World is Real

The object of study, whether humankind or the physical world, is real; that is, it exists apart from and can be observed objectively by the investigator. Although human perception and understanding are flawed and often incomplete, the systematic accumulation of knowledge enables us to know the world and how it works.

The World Can Be Measured

All phenomena can be measured for the purpose of gaining knowledge. Particularly in the social sciences we are confronted with tremendous challenges in finding valid measures for multi-faceted and often difficult to define phenomena such as human personality, emotional states, economic development, and political power. However, all phenomena produce specific values for which valid measures can be developed. These measures can be formalized for use in scientific investigations. Although all measurement contains error and can therefore be infinitely refined, values can be produced which are sufficiently accurate to be applied in research contexts.

The World Functions According to Causal Principles

The world is not random, but functions according to patterns. These patterns can be uncovered through the systematic acquisition of knowledge and formulated in

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cal model in the health sciences or *behaviorism* in psychology. The labels are often applied by critics to a particular paper or method and therefore relate to a specific disciplinary discourse. Authors accepting the dominant paradigm rarely use a label to describe their underlying approach.

terms of general *causal laws*—or, as more commonly formulated in the social science literature, *causal principles*. These principles—which are universally valid, regardless of culture, time, or place—are incorporated into theories which can be expressed in formal symbolic terms (mathematically).

Causal Principles Can Be Described in Linear Terms

The principles governing the patterns in the world (including human behavior) are linear, or at least can be adequately approximated through linear models. This means that the single causal factors which determine the pattern are *additive* and the changes exerted on the pattern as a whole by changes in any single causal factor are *proportional*.

Most simply stated, a linear relationship is one in which A causes B, B causes C, and C causes D. Or, in regard to one phenomenon with multiple causal factors: A combined with B and C causes D. In more formal terms, the latter can be stated mathematically, as in a linear regression model: $D = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \epsilon$ (where ϵ is the error term). Statements of this kind are *additive* in that the individual components or causal factors can be measured separately and combined together to give us the whole picture; in other words, the whole (the phenomenon of interest) is the sum of its parts (the causal factors). These statements are *proportional* in that small changes in one of the factors will produce small changes in the phenomenon of interest; whereas, larger changes will have greater effects on the phenomenon. These properties can be demonstrated through a concrete example from a previous study of the author (Wright 2000d). In this study it was hypothesized that gay men in Germany suffer trauma reactions due to experiences with the HIV/AIDS epidemic. The resulting regression model proposes that: (A) having lost a partner or close friend to AIDS + (B) denying the effects that AIDS has on one's life + (C) experiencing a general sense of demoralization explains or causes (=) (D) trauma symptoms. The trauma symptoms cannot be explained to a large degree by any one of these factors, but is best viewed as a phenomenon arising from the combination of all three, each of which was conceptualized and measured separately. Any increase in one of the factors (for example showing more denial or more demoralization[7]) will be reflected in increased trauma symptoms (to the extent that the particular factor contributes to the

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[7] Factor A is dichotomous; either the subject lost a partner or close friend to AIDS or not. Therefore, there can be no quantitative increase or decrease in the value of the variable.

model). The causal principles being demonstrated in the model are described by survival syndrome theory.

A further implication of the additive nature of linearity is that parts of a larger body can be examined in order to determine the workings of the body as a whole, an approach often referred to as the *analytic method*. For example, the sexual transmission of HIV/AIDS in a population, a phenomenon occurring at the collective level, is most often measured through surveillance data based on the behavior and socio-demographic characteristics of individuals in the population. This is the case in the national survey on gay men and HIV/AIDS in Germany conducted in regular intervals by Michael Bochow (2000b) which is based on questionnaires filled out by individual men. Information on risk behavior, social status, HIV testing, etc. is entered in one data set then analyzed by identifying associations between variables at the individual level as aggregated in the sample. These associations are interpreted as representing broader trends in the population. Once again, the additive principle allows for the whole being viewed as the sum of the parts, here the "whole" being the collective of gay men and the "parts" being the individual men themselves.

A final implication of linearity is the concept of *linear causality*. As the examples stated above show, a linear model poses that there are discrete *causes* and *effects*. Although the causes may interact with each other as proposed in more elaborate models, the influence exerted remains in one direction, that is, from the cause to the effect. This is commonly stated in statistical models by specifying *dependent* and *independent variables*.

Events in the World Can Be Predicted

If the world is real and functions according to patterns which we can identify, measure, and formalize into causal principles, it follows that events are predictable. Indeed, linear models lend themselves directly to being used in a predictive sense in that the probable effects of specific causal factors can be traced alone and in combination with other variables in statistical relation to the outcome of interest. Few scientists today would claim an absolute ability to predict outcomes, particularly in the case of multiple causal factors. Rather, researchers estimate the probability of the outcome given a certain constellation of parameters. This principle is an important component of *evidence-based medicine*, which promotes medical decisions being based on probability statements generated through the appropriate synthesis of clinical research (cf. Sacket et al. 1996). A further example of this approach is the Bernoulli-Process Model of Steven D. Pinkerton and colleagues (1998) which estimates the cumulative probability that an uninfected person with a given sexual profile will become infected with HIV over a particular period of time. The sexual profile includes the number of sexual acts, number of partners, condom use, etc. and the associated probabilities of an infection which each of these factors presents. The overall risk for transmission is then modeled, based on particular behavior scenarios.

The Experiment is the Gold Standard for the Acquisition of Knowledge

Causality cannot be assumed on the basis of association but can only be demonstrated through the use of the experimental method. Within the public health context, this approach is generally referred to as the *randomized clinical trial* or *RCT*. The method requires the random sampling of subjects and their assignment to experimental and control groups, as well as the administration of the intervention in such a way that neither the intervening persons (e.g., physicians or public health workers) nor the subjects can detect who is receiving the intervention being tested and who is not. All other forms of research are seen as containing bias which compromises the reliability and validity of the study, ultimately severely limiting the generalizability of the results in terms of universal causal principles.

Future Change is Contingent on the Current State of a Phenomenon

The concept of change being contingent on the present follows from the view that outcomes of phenomena are predictable. The past, the present, and the future of a particular phenomenon are bound by causal principles which can be discovered, organized into theories, and operationalized in terms of specific models. The causal principles themselves are time invariant, reflecting dynamics which are constant. This means that the present state of a phenomenon contains all the information needed to determine the operative causal principles. Of course, many phenomena (for example, pathogenic processes) need to be observed over time to gather sufficient data. This is because the phenomenon of interest takes time to develop; the causal principles remain, however, unchanged throughout the process.

4.1.2 Alternatives to the Dominant Paradigm

There are, of course, alternatives to the dominant paradigm. Within the social sciences the most common of these approaches can be grouped under the ideal typical categories *interpretive social science* and *critical social science* (cf. Giddens 1978; Phillips 1971; Harre 1972; Suppe 1977; Neuman 1997).

The interpretive tradition can be traced back to Max Weber and Wilhelm Dilthey. It was Dilthey who argued that *Naturwissenschaften* are to be distinguished from the *Geisteswissenschaften*, in that the former focus on *Erklärung* and the latter on *Verstehen*. Weber also promoted *Verstehen* as the basis for social science, whose object of study he defined as *meaningful social action*. The interpretive approach is associated with *hermeneutics*, *constructionism*, *ethnomethodology*, and *symbolic interactionism,* and most commonly employs qualitative methodologies which focus on uncovering the meaning of particular social phenomena in specific historical and cultural contexts. As noted in Chapter 3, the interpretative tradition has had a leading influence on German social science, including evaluation research (Heiner 1992; see also Kelle & Erzberger 1999).

Many associate the critical tradition most closely with Theodor Adorno and the *Frankfurter Schule*. However, in the broadest sense, the tradition draws from such diverse theorists as Karl Marx, Sigmund Freud, Erich Fromm, Herbert Marcuse, Jürgen Habermas and Paulo Freire. From a critical perspective, the primary purpose of social science is the transformation of society by removing illusions, describing structural patterns, and providing a basis for enacting collective change. The critical tradition is associated with *dialectical materialism*, *class analysis*, *structuralism*, *empowerment theory,* and *feminist theory*. The practice of critical social science employs a variety of methods aimed at critiquing the current social order by providing an understanding of the underlying social structures. The goal is to provide the necessary knowledge so that society can be changed to embody particular values. These values vary depending on the orientation of the researcher (e.g. the removal of class-based barriers from a Marxist/Leninist perspective, or gender equality from a feminist view).

Over the last several decades, *feminist* and *postmodern* approaches have gained currency, adding additional perspectives to the question of what social science is and what it can achieve (cf. Olsen 1994; Roseneau 1992; Neuman 1997; Byrne 1993; Cilliers 1998). Although *feminist theory* can be seen as a specific expression of the critical tradition, it has been evolving into a unique and independent perspective. Feminist social science examines social phenomena from a *gender-based perspective*, focusing on the power dynamics between men and women, the influence of gender on a person's experience of reality, and the *unique perspectives of girls and women*. Methods of acquiring knowledge have been developed which directly reflect ways of knowing more common to women and which are generally underrepresented in the sciences as a whole. *Postmodernism* is by definition a rejection of all ideologies and organized belief systems, so it cannot be defined per se as a unified approach to social science research. Theorists who are generally recognized as postmodern thinkers are characterized by their rejection of *modernism*, which essentially means a rejection of the following: logical reasoning as a basis for knowledge, optimism about the future, a belief in scientific progress, and humanistic values as a basis for interaction. Post-modern writers *deconstruct* social phenomena to their constitutive parts in order to expose the ultimate contingency of all perceptions and belief systems on particular experiences of specific individuals or groups. Many postmodern critiques emphasize that all reality, including social reality, is constructed by individuals and groups for their own purposes, thus rejecting outright the validity of such concepts as truth, rationality, reason, and common values.

As diverse as the alternative approaches are, they have in common (1) a rejection of the dominant paradigm and (2) an attempt to define approaches which reflect the unique aspects of social reality (as opposed to the physical world), rejecting a so-called *scientism* or "*physics-envy"* which portrays the natural sciences are being the model of how all science should be conducted.

4.1.3 Critique of the Dominant Paradigm

The specific aspects of the critique of the dominant paradigm can vary widely, depending on the which alternative approach is being applied. Indeed, it is precisely the particular challenge posed to the dominant paradigm which often distinguishes a specific approach from other views. However, there are common criticisms, regardless of approach, which can be summarized here (cf. Kellert 1993, Giddens 1978, Neuman 1997, Byrne 1998, Kießling 1998, Phillips 1971):

The Individualistic Fallacy: The individual person is the object of theory and research

Research on social phenomena within the dominant paradigm is most often confined to collecting data on individuals and aggregating this data to define the phenomena in question. Social trends are thus analyzed as being the accumulated result of actions and tendencies at the level of individuals living within a society. This approach, which has been called *the individualistic fallacy* (in reference to HIV see Davies, et al. 1993 and Fee & Krieger 1993; see also Tesh 1988), ignores dynamics which exist outside of individual persons and thus provides little insight into larger forces which shape humankind at the interpersonal and collective levels, for example: couple dynamics, familial relationships, class difference, systematic discrimination, restricted access to resources, social movements, and political power. These dynamics affect individuals and are co-created by individuals, but they have features which can only be explained at a higher level of organization.

Reductionism: Social phenomena are reduced to a small number of specific factors

Social phenomena are the result of numerous influences on several levels: political, familial, interpersonal, psychological, economic, etc. Each of these levels is, in turn, multi-faceted. For example, the psychological aspect of social phenomena is composed of rational, affective, behavioral, and symbolic elements. Social phenomena are, therefore, generally the result of a multitude of factors on several levels coalescing at a particular moment in time. The theories and models generated within the dominant paradigm tend to explain social phenomena by focusing on a very limited number of factors usually confined to one level and are therefore *reductionist*, failing to describe meaningfully the phenomena as a whole by focusing only on certain parts.

Determinism: Causal explanations are deterministic and mechanistic

The dominant paradigm produces causal explanations for social phenomena which treat the individual person and society as machines which work according to set structures and rules, ignoring such dimensions as *consciousness*, *self-reflection*, *agency*, and *free will*. These explanations are often criticized as promoting a *"mechanistic"* view, reflecting a belief in a *"clockwork universe."* A clock is driven to function in precise ways by mechanisms beyond its control because these mechanisms constitute its very nature. Such causal explanations are also described as *deterministic*, as there is no room provided for change based on human creativity, insight, or communal action.

Decontexualization: Ultimate explanations are proposed at the expense of contextual difference

Research conducted within the dominant paradigm strives to produce causal explanations for social phenomena which apply to humankind, in general, or to large categories of people (e.g., women, youth, gay men, etc.). In doing so, phenomena are *decontextualized*; that is, they are depicted as existing outside of culture, individual circumstances, class difference, etc. This tendency to over-generalization results in theories and models with limited application. Such theories ignore important elements of specific situations which need to be taken into account in understanding a social phenomenon as it occurs at a particular time and in a particular place.

A further implication of decontextualization is overlooking the *meaning* which social phenomena have for individuals and groups. The meaning of a phenomenon affects how it is experienced and how those involved respond. A social phenomenon (such as an epidemic) may have nearly identical structural features in two different settings, but mean very different things to the groups affected and thus lead to very different responses.

Reification: Theories and models are treated as being real and as existing apart from the researchers themselves

There is a tendency when working within the dominant paradigm to view constructs produced for theoretical and research purposes as reflecting the real social phenomenon under study, so that the two are interchangeable. In other words, the constructs tend to be *reified* by the researcher. This occurs as a result of the aforementioned reductionism and due to a lack of critical distance on the part of the researcher regarding the various influences on how a particular phenomenon is defined and measured. Social phenomena can only be approximated by the creation of various constructs. It is not possible, for example, to say that a particular marital conflict scale is measuring the overall quality of a couple's relationship; such a phenomenon is far too multi-faceted to be confined to any particular definition or operationalization. At best, one can claim that a construct is useful when examining a particular phenomenon, but the phenomenon itself is always greater than that which can be measured.

Ahistorical Perspective: Causal explanations do not take into account changes over time which affect the nature of social phenomena

Indeed, the dominant paradigm is interested in the longitudinal development of the phenomenon under study, particularly in terms of following and predicting outcomes over time. The problem addressed in this critique is the focus on *quantitative changes* over time while ignoring *qualitative changes*. That is, changes in values on certain measures are monitored over particular time spans, but the assumption is made that the underlying causal principles and the general nature of the phenomenon are not changed within that period. The result is that research conducted under the dominant paradigm tends to make causal statements which are *ahistorical*. The assumption is made that the particular constellation of factors producing the specific outcome will, under a certain probability, always produce that outcome under comparable circumstances. The potential for a qualitative development (an evolution) of social phenomena, and therefore of their respective causal properties over time, is thus not taken into account.

Illusion of Predictability: The ability to predict social phenomena is limited

Predicting outcomes of social phenomena is a central goal of the dominant paradigm. This ability to predict validates the causal principles as articulated in specific theories and models and allows for the direct use of research findings in designing interventions to steer the course of events. According to the critique, the ability to predict such phenomena is severely limited because of their emergent, historical nature and their multi-faceted structure. The causal models proposed tend to be oversimplified representations of the phenomenon of interest. What they can predict is therefore limited to specific aspects of the phenomenon in question, but not the course of real events as they unfold.

Lack of Resemblance to Reality: The models proposed bear little resemblance to the phenomena under study

It follows from the above criticisms that the detractors of the dominant paradigm draw attention to the discrepancies between the models proposed to describe social phenomena and the phenomena themselves. In other words, the models are not *isomorphic* with the social reality they claim to describe. Even elaborate models which incorporate a multitude of factors fail to offer meaningful explanations because of fundamentally flawed assumptions regarding causality, prediction, history, etc., as detailed above.

Given this critique and given the fact that there are well-established alternatives, why does the dominant paradigm continue to exert such an overbearing influence within the social sciences? A thorough exploration of this question would take us beyond the scope of the present work. The answer is likely to include reasons which have to do with the search for credibility and support on the part of the social sciences, the general philosophical and ideological trends found in modernism, and the politics of science itself. Drawing on several historical analyses, W. Lawrence Neuman (1997, p. 67) provides an interesting answer, reflecting these various elements:

> *When and why did positivist social science become dominant? The story is long and complicated. Many present it as a natural advance or the inevitable progress of pure knowledge. Positivist social science expanded largely due to changes in the larger political-social context. Positivism gained dominance in the United States and became the model for social research in many nations after World War II, once the United States became the leading world power. A thrust toward objectivism—a strong version of positivism—developed in the U.S. sociology during the 1920s. Objectivism grew as researchers shifted away from social reform-oriented studies with less formal or precise quantitative techniques toward rigorous techniques in a "value free" manner modeled on the natural sciences. They created careful measures of the external behavior of individuals to produce quantitative data that could be subjected to statistical analysis. Objectivism displaced locally based studies that were action oriented and largely qualitative. It grew because competition among researchers for prestige and status combined with other pressures, including funds from private foundations (e.g., Ford Foundation, Rockefeller Foundation), university administrators who wanted to avoid unconventional politics, a desire by researchers for a public image of serious professionalism, and the information needs of expanding government and corporate bureaucracies. These pressures combined to redefine social research. The less technical, applied local studies conducted by social reformers (often women) were often overshadowed by apolitical, precise quantitative research by male professors in university departments.*

4.2 Complexity Theory: Definitions

It has become commonplace, both in everyday conversation as well as in scientific discourse, to describe the world and its problems as "complex." What is usually meant is that there are no simple explanations, that we need to take into account several factors to find out what is really going on. The term *complex* also has a more formal definition arising from the emerging perspective known as *complexity theory*. Here we will define some of the basic components of this theory.

The discussion of complexity in the terms defined here was catalyzed in the social sciences by work done in the natural sciences over the last forty years, particularly in physics beginning in the 1980s. The body of work in the natural sciences examines non-linear dynamical physical systems and their properties. Important examples have come from meteorology and hydrodynamics but have also included the study of such phenomena as lasers, chemical reactions, pendulums, and even dripping faucets (see Haken 1987, Prigone & Stengers 1984). The major insight shared by the various researchers is that non-linear dynamical systems do not follow patterns predicted by the physical laws used to describe linear phenomena. It is these laws which have dominated the study of physics, in particular, and the natural sciences, more generally. This basic observation has led to a new field of investigation which has revealed qualities of the physical world which were previously unknown or seldom studied. The insights gained from this research have generally been subsumed in the natural sciences under the name *chaos theory* or *complexity theory*.

The concern for complexity is, however, not new to the social sciences. It is precisely this concern which has motivated theorists over the last two centuries to develop approaches which take into account the multi-faceted nature of social phenomena. In describing complexity theory in the context of social science research, these traditions must also be examined.

Before proceeding it is important to offer an initial answer to the question: Why complexity theory? If, as stated above, there are several alternative scientific paradigms to choose from which specifically address the social world, why introduce yet another theoretical structure? It will be argued here and in the remaining chapters that public health, as an applied field incorporating several disciplines from the natural and social sciences, needs theories which allow for a dialogue between these disciplines. Public health problems are, by their very nature, *biopsychosocial* problems

(Engel 1977, 1980). One of the most interesting and important aspects of complexity theory is that it allows for such a dialogue. The theory provides a structure within which several disciplines can interact in order to better describe complex phenomena which impinge on the public's health (like epidemics of contagious diseases) so that interventions can be designed which take into account this complexity. In addition, it will be proposed that complexity theory offers a basis for conceptualizing and implementing evaluations of such interventions. Complexity theory poses, then, an alternative to the dominant paradigm described above, but one in which the natural and social sciences can find common ground.

Another reason for complexity theory and its largely quantitative orientation is that it provides a basis for population-based approaches which, at the same time, do not exclude the subjective element. Public health is by definition focused on the societal level of problem analysis and intervention, not on the individual case (cf. Pearce 1996).

It is important to recognize that complexity theory is a new, emerging approach. Although certain concepts and applications are well-established, complexity theory as a coherent, unifying explanation is still at an early stage of development. The description presented here reflects common elements found within the complexity literature, particularly as used by social science researchers and theorists.

4.2.1 What is Complex?

What does *complex* mean, in the formal sense? Paul Cilliers (1998) answers this question by describing ten characteristics common to all complex phenomena. These ten characteristics can be adapted for our discussion and summarized as follows (cf. Byrne 1998, Kießling 1998, Kiel & Elliot 1997, Masterpasqua & Perna 1997):

1. A large number of elements are involved

   The phenomenon is produced by a large number of individual parts or factors.

2. The elements interact dynamically within a system

   A large number of elements are not necessarily capable of producing complex phenomena. The elements need to be organized in a *dynamically interactive system*. *Interaction* means that there is contact between the elements in terms of sharing some form of information. A *system* implies a group of elements which interact in such a way as to produce a cohesive whole. The *dynamic* nature of the interaction means that the system changes over time.

3. The individual elements tend to interact with several other elements

The resulting system is not one in which, for example, element A interacts with element B which interacts with element C, etc., but rather is characterized by more elaborate or *rich* patterns of interaction in which each element is connected to several others through the exchange of information. These patterns can be described as *networks* of exchange.

4. The interaction between elements is non-linear

A non-linear interaction results in phenomena which cannot be described using *additive* models. In addition, the influence of any singular element is not *proportional* (see above definition of *linear*). This is the case because *reciprocal causality* (as opposed to *linear causality*) is operative. The two major implications of non-linearity are (1) the phenomenon as a whole cannot be adequately understood by examining its individual parts and (2) small changes in any one of the elements can result in large changes regarding the phenomenon of interest. Non-linearity is a direct result of the mutual influence between variables found in systems with rich patterns of interaction. In such systems, clear causal chains cannot be traced because of multi-directional and multi-factorial influences at all stages, from the germination of the phenomenon to its expression.

5. Elements interact within a nested hierarchy of levels

The system is comprised of various levels of interaction which are imbedded one within the other according to a specific hierarchy (like Chinese boxes or Russian matroyshka dolls). Elements tend to interact with each other at the same level of organization. The effects of an element can, however, reach through the various levels of interaction to affect the phenomenon in question. Such an influence is, however, mitigated by all levels further out on the hierarchical structure. (cf. the discussion of Susser & Susser 1996 on the future of epidemiological theory in which the same metaphor of Chinese boxes is used.)

6. The interaction between elements is influenced by feedback loops

The effects of any interaction can feed directly back to the elements involved, either in the form of *positive feedback* (i.e., enhancing or stimulating the initial effect) or as *negative feedback* (i.e., reducing or inhibiting the initial effect).

7. The interactions take place within an open system

   An *open system* (also called a *dissipative* system) interacts with its environment through various exchanges of energy or information. This means that the environment also has an influence on the phenomena generated by the system.

8. The interactions take place within a system which is far from equilibrium

   A system in *equilibrium* is in a non-changing (static) state which is characterized by the system having no exchange with its environment. A system described as *near equilibrium* is one which is not static, but tends toward homeostasis. In contrast, an open system tends to be *far from equilibrium* which means that it is in a constant state of change based on a high level of energy or information exchange with its environment.

9. The interactions have a history

The interactions which are taking place at any moment in time have evolved from a previous moment in time; that is, the interactions are contingent on an historical process. A description of interactions happening at any given moment is necessarily incomplete because the changes over time are not taken into account.

10. The elements function as a network without specific elements exerting a central control

The individual elements do not interact based on comprehensive information about what is happening to the system as a whole, but rather on locally available information from neighboring elements. The complexity is, therefore, a structural characteristic arising from interactions of dispersed but richly connected elements and not the result of a centrally coordinated process steered by “key” or “controlling” elements.

To sum: A complex phenomenon is one which results from **interactions** between **a large number of elements** occurring within a **dynamic, open system**. The individual elements function as a **network**, with no one element controlling the system as a whole. The interactions are characterized by **non-linear patterns** and **feedback loops**, and they occur at various levels within a **nested hierarchy** of elements.

The system as a whole is a product of its **history** and functions **far from equilibrium**.

A short-hand designation for complex phenomena often found in the literature is *complex adaptive systems*, a term standing for the above definition and associated dynamics.

Before we proceed in concretizing this rather abstract definition, it is useful to consider two points in discerning whether a phenomenon is complex. The first is the distinction between *complicated* and *complex*. There are many phenomena which have several elements, but which do not fulfill all of the criteria above. *Complex* is more than a collection of many related elements; it is, rather, a structural characteristic which arises from elements interacting in the specific ways listed above. The second point is the matter of scale. As Cilliers (1998) illustrates, when viewed from a particular "distance" an object or phenomenon can appear simple, but when examined more closely a complex structure is revealed—and vice versa. He gives the example of a leaf. From afar, it is a simple, everyday object with recognizable, readily describable features. But when, for example, the leaf is viewed under a microscope or as part of a larger plant, the complexity of the leaf becomes apparent at various levels of interaction. An opposite example is that of an automobile engine. Although consisting of many parts, the functioning of an engine can be fully described using conventional linear explanations. An engine can, indeed, be complicated, but the role of the individual elements is traceable and analyzable without recourse to complexity.

In general terms, the above definition of complexity implies that all living things and their interactions constitute complex systems, for example: animals, the brain, disease processes, and social interaction. On the other hand, only some inanimate objects may be classified as such. Single objects consisting of a few parts lack in complexity, for example: a pencil, a mirror, and a towel. Other objects, as mentioned above, are complicated, but not complex: a radio, an engine, a television. The advent of computers has created machines which have begun to imitate human intelligence and are thus difficult to categorize in terms of complexity; in fact, the debate concerning the future of artificial intelligence has to do with this very issue (Cilliers 1998).

At this point it is helpful to take real life examples from public health in order to demonstrate what is meant by a complex phenomenon.

Nancy Krieger (1989, 1994) has proposed a model of breast cancer which demonstrates the complexity of this disease phenomenon (Figure 4). In her work, Krieger is arguing for a more comprehensive understanding of breast cancer etiology by incorporating social factors as part of the explanation. Although Krieger does not formally base her model on complexity theory, the various components fit well into the above definition.

1. A large number of elements are involved

Breast cancer is the result of several factors including, for example, work exposures, social background, and reproductive history.

2. The elements interact dynamically within a system

The various factors do not interact in a simple causal chain, but influence each other in various ways to produce the outcome. For example, the socially-mediated risk affects reproductive factors and events which also mutually influence each other. The dynamic aspect of the system is apparent in the age dependency of the reproductive factors and events; that is, the timing of these factors and events within the overall system can influence the occurrence of breast cancer. Also, the age of exposure to exogenous carcinogens plays a role.

3. The individual elements tend to interact with several other elements

As stated above, the various factors do not interact in a simple causal chain. There is, rather, a network of influences which can come together to produce altered breast tissue and lead to cancer.

4. The interaction between elements is non-linear

There is an implicit non-linearity in Krieger's model in that she argues for reciprocal causality in terms of exposure and susceptibility co-determining the outcome of breast cancer. In a strictly linear model, the effects of exposure and susceptibility could be analyzed apart from one another and combined to explain the phenomenon of interest. But within Krieger's model we find the interrelationship of both by way of common origins in socially-mediated risk factors. Thus, one cannot separate exposure from susceptibility when seeking to explain the occurrence of breast cancer.

5. Elements interact within a nested hierarchy of levels

The diagram of the model clearly depicts a hierarchy of interactive levels which can produce the phenomenon of breast cancer. At the most basic level we have the technological and social environment in which women live; this level can be pictured as the largest of the Chinese boxes, containing all other boxes inside. The next box would be the particular class, race and gender divisions characteristic of women's environment. At the next level we find reproductive factors, exposure to exogenous carcinogens, and dietary factors. Then comes the level of the body which includes breast tissue proliferation/differentiation and genetic factors. The next level is composed of accumulated exposures and susceptibilities which would represent the immediate causes of pathogenesis. The resulting breast cancer is not a level, but is the phenomena generated by the combined output of the multi-level system as a whole.

6. The interaction between elements is influenced by feedback loops

Feedback loops are not explicit within the proposed model but are implied by Krieger's insistence on the historical nature of the phenomenon. Krieger's narrative description emphasizes the need to examine the interplay between exposure and susceptibility throughout a woman's lifecycle, implying that previous interactions among factors influence later interactions, with cumulative effects feeding back to the larger system to affect the outcome.

7. The interactions take place within an open system

The model is clearly based on a system which is in active exchange with the social and physical environment which thus, in turn, influences the resulting exposures and susceptibility of women.

8. The interactions take place within a system which is far from equilibrium

As Krieger (1989, p. 211) states: "This alternative hypothesis consequently implies that the presumed joint determinants of breast cancer incidence—exposure and susceptibility—cannot be examined statically, but instead must be considered in relation to each other at every stage in a woman's life." The constant change and evolution of the system is thus important.

9. The interactions have a history

The above quotation reveals the explicit historical nature of the model.

10. The elements function as a network without specific elements exerting a central control

The model includes a host of factors without attributing a controlling or steering function to any one of them. It is the co-joint activity of these factors among the various levels which can produce the cancer outcome.

Another example is the explanation of tuberculosis (TB) epidemics provided by David Byrne (1998) which is a direct application of complexity theory to this disease phenomenon:

1. A large number of elements are involved

TB epidemics result from several factors, for example: the presence of the TB bacillus; the lack of immunity to TB in individual persons; genetic resistance in certain individuals; the lack of prior exposure to TB within households; the prevalence of TB within the community; the socioeconomic environment (housing, nutrition), etc.

2. The elements interact dynamically within a system

The various factors cannot be viewed in isolation but rather work together to produce a TB epidemic. For example, the presence of the bacillus alone in a population does not lead to an outbreak; a combination of factors is necessary. The interaction of the various factors changes through time, depending for example on changes in the living conditions in a community.

3. The individual elements tend to interact with several other elements

Byrne's explanation makes clear that there is rich interaction between various elements. For example, poverty in a community not only effects the quality of the places where people live (how many persons to a room, level of hygiene) but also how well people eat. The prevailing social and economic policy not only affects the income of individual's and households, but also has an influence on what resources are available to communities as a whole (housing stock, etc.).

4. The interaction between elements is non-linear

Just as in Krieger's model of breast cancer etiology, we find here an implicit non-linearity in that reciprocal causality is key in determining to what degree TB spreads in a population. It is not a particular chain of events or factors which leads to an epidemic, but an interdependent co-occurrence which decides the outcome. The individual factors can therefore not be separated because of the mutual influence which they exert on each other.

5. Elements interact within a nested hierarchy of levels

Byrne explicitly describes the four levels of the nested hierarchy operative in TB epidemics: the individual (immunity, including genetic resistance); the household (living circumstances and nutrition within families; degree of previous exposure); the community (strength of economy, income level of neighborhood or district); the nation state (policy affecting social and economic conditions).

6. The interaction between elements is influenced by feedback loops

Feedback loops are implicit in Byrne's description. For example, he describes TB outbreaks in the period between the World Wars in the UK as being part of the generally poor living conditions of major sections of the population. This gave impetus to communal action in order to improve housing conditions. The improved housing conditions contributed to the victory of the Labour Party in 1945. This period also marked the establishment of new social structures within that country. We see in this example that housing conditions and policy are so interrelated that one cannot be seen as causing the other; rather, the interaction between the two influences show how housing conditions and policy affect each other.

7. The interactions take place within an open system

The system of interactions is one which involves an active exchange with the social and physical environment which results in a changing interplay between the various factors.

8. The interactions take place within a system which is far from equilibrium

Several factors which contribute to a TB epidemic can change at any point producing a new dynamic for the spread of the disease. These changes are due, in large part, to the exchange between the interactive system and the environment. For example, changes in housing policy, in the composition of the community, or in the patterns of contact between people can affect the network of interactions underlying the epidemic.

9. The interactions have a history

The various factors develop over time and change in their interactions with one another, accordingly. For example, genetic resistance within a population is an evolutionary process which takes place over several generations. In addition, the social and economic conditions of a community result from particular constellations of policy and specific events.

10. The elements function as a network without specific elements exerting a central control

Byrne's explanation includes a host of factors without attributing a controlling or steering function to any one of them. It is the co-joint activity of these factors among the four levels which can produce a TB epidemic.

4.2.2 Complex Phenomena and Change

Complexity theory not only offers a definition of what is *complex* but also provides a description of the unique dynamics found within complex phenomena. These dynamics will be discussed under the following headings:

- state space
- attractors
- bifurcation
- self-organization (autopoesis)
- evolution
- chaos
- self-similarity

State Space

A complex phenomenon can dramatically change its state (or shape) over time. This change can be conceived of as taking place within a particular space which can be described metaphorically (and mathematically) as consisting of several dimensions. The classic examples of state space from the natural sciences plot three dimensions over the course of time, producing geometric forms which are used to study complex dynamics, more generally (e.g. Lorenz 1963, Nicolis & Prigone 1989). Interestingly, even in three dimensions, a large range of complex dynamics can be observed. Such simplified models can also be used to study the basic dynamics in complex social systems (e.g. McBurnett 1997). In this discussion we will, however, assume a state space as having more than three dimensions, thus reflecting the more typical models of phenomena within the social sciences.

It is not easy to picture dimensions above three, given the usual limits imposed by language and perception. It is far easier to imagine linear relationships which can be drawn as a flow chart or symbolically represented in the form of an equation. The challenge here is to depict several dimensions simultaneously in such a way as to describe the structure of the phenomenon of interest as it moves across these dimensions in time.

David Byrne (1998) suggests re-thinking the common contingency table (cross-tabulation of multiple variables) to be a representation of the various states possible for a given phenomenon. This would mean that n variables represent n dimensions of the phenomenon under study, and these dimensions combine to show the contours of the phenomenon.

Byrne applied this idea to census data from 1977 to 1995 for a city in the UK, tracking patterns of social class, household composition, and work status. Analogously applying this idea to typical variables regarding sexual behavior and HIV risk, we could name the following four dimensions for a surveillance study of sexually active adults, simplified here for the purposes of illustration:

age	(e.g. four categories: youth, young adult, adult, older adult)
primary protective behavior	(e.g., three categories: abstinence, steady relationship, condom use)
social class	(e.g. three categories: lower, working-class, middle class or above)
HIV status	(e.g. three categories: positive, negative, untested)

The phenomenon of interest is how those surveyed respond to HIV risk at the population level. Each possible combination of the variables would not represent a "profile" of particular individuals, but rather the ways in which the dimensions combine to express the phenomenon in question. The above four variables with their combined total of thirteen possible values yields a total of 108 potential combinations or states of the phenomenon risk response in the population. Of course, even in a sample of 108 or more we would not find cases in each of these possible states, because at any one time the phenomenon only expresses itself in specific value combinations of the various dimensions. This is, itself, an important insight into the phenomenon; the low occurrence of certain combinations reflects the structure of the phenomenon. By using appropriate statistical analyses, we can see which dimensions and which values of those dimensions tend to combine. These combinations represent constellations which define the contours of the phenomenon at that moment in time, in other words, the phenomenon's state space. By comparing cross-sectional data of this nature over the course of time, we can observe shifts in these constellations and thus gain insight into the dynamics of the phenomenon as a whole.

Another way of conceptualizing state space has been proposed by Lewis and Junyk (1997) in their application of complexity theory to human personality. They use the image of a landscape on which many hills and valleys of various sizes and shapes appear, these representing the states which people can exhibit in their emotional and social behavior. Changes in state are like a ball moving across this landscape, the ball being repelled and attracted according to the contours of the place in which the ball is located. The personality landscape defines all possible states for the person and thus defines the "space" in which personality operates and expresses itself. (cf. *fitness landscapes* below under "Evolutionary Theory")

Attractors

As described above, a complex phenomenon is constrained at any given point in time to particular states. These states are known as *attractors*. If we picture the phenomenon as moving among its various dimensions in the state space over time, we can conceive of the phenomenon being "pulled" or "attracted" to certain states over others, hence the name.

Bifurcation

The constellation of attractors as well as the relative importance of each can change over time. A qualitative change in a complex phenomenon of this sort is known as a *bifurcation*. The literal meaning of the word bifurcate (to divide into two parts or branches) provides a useful image for clarifying what is meant here. Essentially, a point of bifurcation is a crossroad at which point the phenomenon reorganizes into something qualitatively different and thus alters its developmental trajectory. Such turning-points are often the result of new information from outside the phenomenon which basically knocks the phenomenon from its previous course and thus permanently changes the dynamic of the phenomenon as a whole.

Self-Organization

The means by which a complex phenomenon reconstitutes itself at a point of bifurcation is known as *self-organization* or *autopoesis*. This means that within every complex phenomenon is the inherent tendency to generate new structures and forms in response to the environment.

Evolution

Complex phenomena are fundamentally developmental in that they are in a never-ending state of becoming. Through self-organization such phenomena reconstitute themselves into ever increasing levels of complexity. The evolutionary process is by definition open-ended and is a result of an ongoing information exchange between the complex phenomenon and the surrounding environment.

Chaos

At times of transition (bifurcation) a complex phenomenon can go through a period of *chaos*, a state which has received much attention in complexity theory. Chaos here does not mean complete disorder and confusion, as the everyday use of the word would suggest. In the formal sense, chaotic behavior in a complex phenomenon is a period in which a regular pattern of attractors within the state space is replaced by random behavior. In such periods it is not predictable how the phenomenon will reconstitute itself. Such behavior is considered by several theorists to be a hallmark of complex phenomena, which is reflected in the term *chaos theory* being used as a synonym for complexity theory, with the emphasis often being placed on the chaotic behavior itself.

Self-Similarity

Complex phenomena are, by definition, multi-leveled. However, the structure of each level often resembles that of the other levels, providing a kind of symmetry which is useful in the search for order in otherwise difficult to comprehend systems. It is this self-similarity of complex phenomena which makes analogous thinking so useful for both artistic and scientific pursuits. A common illustration of this feature of complex phenomena is the organization of society. The basic structures (relationships) within a biological family (mother, father, son/daughter, sibling) constitute forms of hierarchy, communication, and intimacy which are reflected within work environments, civic organizations, governmental structures, and international relations. This is described linguistically through such terms as *parent company*, *sister cities*, *political marriage*, and *mother country*.

To sum: The dynamics of a complex phenomenon are organized by **attractors** into specific states at any given moment, the collection of all possible states constraining the phenomenon to a particular **state space**. This state space changes over time, however, as a complex phenomenon evolves and thus achieves an increasingly complex structure. This **evolution** is characterized by **bifurcation** points which can be accompanied by periods of **chaos**. Complex phenomena are in a constant process of **self-organization**, incorporating all new and existing information into various forms and structures at all levels of organization. As complexity increases, each new level bears structural resemblance to all previous levels, and thus **self-similarity** can be observed.

Again, we will use concrete examples from public health to make this abstract description of complex dynamics understandable.

We begin with Byrne's example of TB as a complex phenomenon. Byrne (1998) describes the development of the TB epidemics in the nineteenth and early twentieth century in the UK when TB was a major cause of death. The evolution of the TB problem can be traced from a low level of complexity (the endemic presence of the bacillus in the population with a low incidence of sickness) to a widespread epidemic with mortal consequences for large segments of the population. Byrne suggests that there are two major **attractors** in the **state space** which describes the spread of TB in industrialized societies: (1) a state in which the bacillus is a major cause of morbidity and mortality and (2) a state in which the bacillus is present in the population but does not result in serious health problems for the vast majority of people. The first attractor includes not only the presence of the bacillus, but also weak immunity in the population and poor living conditions which hinder the provision of clean water, food, and a well-ventilated and sanitary living environment. These poor living conditions are particularly present when immigration, material poverty, and social inequality are pronounced. The second attractor also includes the presence of the bacillus, but the population is characterized by a higher level of immunity and a higher standard of living. This standard of living is supported by structures which promote economic equality and material security. As the description of the two attractors suggest, the epidemic operates on four levels which develop over time as the epidemic progresses. This development is marked by **bifurcation** points which affect the trajectory of the epidemic's **evolution**. At the individual level, the first bifurcation point is exposure, that is whether or not the individual carries TB. When the bacillus is present in individuals, the next bifurcation point in the development of the epidemic is the degree to which households contain one or more members with TB as well as the living conditions of the household. If many households become infected and their living conditions are poor, whole communities are affected, which marks the next bifurcation point. Finally, if the social and health structures of the region and country do not provide adequate safeguards to prevent inequality and material poverty, the localized epidemic becomes a national problem, marking the last major bifurcation point. The characteristic of **self-similarity** is clear, for example, in the way in which social disadvantage is operative on all four levels. The **self-organizational** aspect is evident in the progression of the epidemic itself, the disease spreading in patterned ways based on the conditions at hand; that is, the epidemic has its own dynamic which can be affected but not controlled by outside agency. Byrne's account does not address the dynamic of **chaos** per se; however, other literature suggests that epidemics can also be characterized by chaotic behavior, resulting in the patterns of disease spread being unpredictable, particularly at crucial points (bifurcations) in the epidemic's development (Philippe & Mansi 1998).

Another example is provided by Glenn Albrecht and colleagues (1998). They describe the complex phenomenon of providing interventions to prevent heart disease among families in Australian coal mining communities. Albrecht, et al. describe four pairs of opposing "social **attractors**" on four levels which have **evolved** over time to characterize the **state space** of the phenomenon (Figure 5). Prior to the 1940s the coal miners and their families were the victims of considerable socio-economic discrimination. At the community level, a sense of solidarity developed based on a differentiation between the people in the coal mining communities and those on the outside. This solidarity **bifurcated** into two opposing attractors: a sort of male solidarity opposing outside influences and a "respectable" response based on the norms of the "outside world." As time went on, increasing unemployment among men and feminist influences from the broader society (including health promotion strategies being initiated by women) resulted in two additional attractors on the level of gender relations: resistance to health messages vs. acceptance of health messages. Later, in light of declining trade unions and a marked epidemic of heart disease, two more attractors emerged: an anti-authoritarian, communitarian view vs. acceptance of the official health promotion campaign focused on individual responsibility. Finally, the creation of community initiatives produced two more attractors: a world view associated with elevated heart disease vs. a world view associated with lower incidence of heart disease. As Figure 5 makes clear, the four pairs of attractors can be viewed as the result of a bifurcation as each new level came into existence, the bifurcation resulting in two opposing, co-existing trajectories through time. The **self-organization** principle is apparent in the response generated by the communities as the various external influences were exerted on them, this response resulting in the formation of new attractors. The **self-similarity** among levels is clear in terms of the bi-polar response which is evident at each stage in the evolutionary process. In their account, Albrecht, et al. refer to the unpredictability of the enfolding dynamic, but without a specific reference to **chaotic** features.

4.3 Sources of Complexity Theory

As stated at the beginning of this chapter, complexity theory is an emerging scientific perspective. As such, there is yet no established canon guiding researchers and theorists in their attempts to explore this theory in terms of their specific areas of interest. This dissertation is itself an attempt to contribute to the discussion of what complexity theory implies for public health, specifically for the practice of community-based HIV prevention.

An interesting feature of complexity theory is that it represents a convergence of thinking from a variety of disciplines. It will be argued in Chapter 6 that this feature makes it possible to use complexity theory as a unifying basis for evaluation research. Here, some of the various sources feeding into the broader discussion of complexity in the social sciences will be presented. This listing is far from complete; however, it does represent several of the main influences shaping the current discourse.

4.3.1 Chaos Theory

By far the most well-known source of theory and method regarding complexity is *chaos theory*, a body of ideas resulting from the study of nonlinear dynamic systems in the natural sciences. James Glieck's (1987) widely acclaimed journalistic account of the development of chaos theory provides an extensive if somewhat messianic description of the major proponents of the theory and their work. A more critical review is provided by Klaus Kießling (1998), organized around the two key concepts of *chaos* and *self-organization*. Notable figures who have contributed to chaos theory and examples of their work include: Ilya Prigogine (1984), Manfred Eigen (1979), Edward N. Lorenz (1963), Benoît B. Mandelbrot (1977), Mitchell Feigenbaum (1978), Hermann Haken (1987), David Ruelle (1989), Steven A. Kauffmann (1993), Mitchell Waldrop (1992), and Humberto Maturana (1982).

Clearly, the initial impetus to focus on complexity as a field of study in social sciences came from chaos research. The most common terms used to describe complex dynamics, as presented above, have their origin in natural science applications, particularly in physics. It is important to note that these terms have very specific formal definitions in their original contexts which are often expressed in terms of mathematical relationships between elements of the system under study. The fact that these relationships have been shown to apply to a host of nonlinear physical phenomena was the first step in moving chaos theory from a curious special interest to being a basis for new areas of theory-building and research regarding long-standing problems in the study of dynamic change processes. Social science researchers influenced by chaos theory are primarily concerned with the direct application of the formal mathematical definitions proposed by the natural sciences to phenomena in the social world. Most importantly, these researchers seek to analyze time-series data using specifically designed procedures in order to identify formally the existence of such features as bifurcation, chaos, and self-organization. In general, these researchers insist on the need for evidence comparable to that found in the natural sciences as the pre-requisite for chaos theory being applied to social phenomena. It follows that their work tends to focus on methodological questions in the collection and analysis of social science data so as to make the production of such evidence possible.

An example of this approach is the work of Michael McBurnett (1997) who has applied complexity theory to the study of public opinion. McBurnett analyzes data from the American presidential campaign in 1984 in order to describe the shifts in public opinion in the period preceding the election. Using time-series data from repeated poll-taking, McBurnett is able to construct a three dimensional picture of the state space in which public opinion changed in the given time period. He is further able to show mathematically that a nonlinear process with chaotic features was operative, thus demonstrating the inadequacy of typical linear models. McBurnett proposes conducting more basic research in political science with the hope of uncovering such patterns elsewhere (p. 193):

> *Where should political scientists search for chaos? Wherever one has a time series the possibility exists that the underlying governing equations are nonlinear. For example, the political business cycle is a good candidate for a nonlinear dynamic process precisely because no one can find a cycle. Instead, what is found is a pattern of aperiodicity very similar to what is found in economic, biologic, and physical systems exhibiting chaos. The political business cycle links the president's popularity with a number of dynamic variables, each of which can be described by a separate equation. [. . .] Perhaps a systematic set of governing equations may be discovered that operate across many electoral levels.*

In this quotation we see features typical for this approach, for example: using specific mathematical relationships across disciplines to describe dynamic patterns; the focus on time-series data (which requires the generation of a large number of data points so as to make the procedures used in the natural science applicable); and the search for a governing set of equations to describe social phenomena better than existing linear models.

Another example of the application of chaos theory to the social sciences can be found in the work of Günter Schiepek et al. as described by Kießling (1998). Schiepek and colleagues are seeking to develop research methods which better describe the process of systemic therapy. In one experiment the researchers record all occurrences of "operators" (gestures, body position, eye movement, and verbal communications) on the part of the client and therapist, resulting in 702 and 301 observations, respectively. These were charted over the course of a short-term therapy in order to depict the dynamic across sessions. The researchers are seeking to identify various relationship states in the therapist/client system over the course of the sessions, including points of bifurcation and signs of chaos (see also Schiepek & Kowalik 1996).

There are, however, several problems inherent in applying the methods of chaos theory in the natural sciences to problems in the social sciences. These can be summarized here based on the comments of Dimitrios S. Dendrinos (1997):

Lack of Data: Few variables in social science are available at frequent enough intervals to gather the accuracy of time-series data required by chaos research. Exceptions include areas of economics, where several indicators (e.g. stock market data, monetary tables) are produced at such frequency and in such detail as to make the use of the various analysis procedures feasible. In the natural sciences, physical experiments are routinely constructed which produce reliable data on dynamic systems over several dimensions.

Frequent Perturbations: Social systems do not produce repetitive measurements under experimentally controlled conditions. Chaos analysis in the natural sciences depends on a certain quality of data which enable the identification of so-called *white noise* from the stochastic features of chaos. Data of this nature is not generally available in regard to social problems.

Inaccuracy: An important observation from the natural sciences regarding nonlinear dynamics is that even small differences in the initial conditions of a dynamic can greatly alter the trajectory of a system's development (see definition of *nonlinearity* above). To distinguish between various initial states, a high accuracy of measurement is necessary. In the natural sciences, such factors as temperature, pressure, density, etc. can be measured very precisely. In the social sciences, measurement is highly imperfect, with the norm being multiple options for operationalizing and measuring any particular quality.

Aggregate Data: The methods for chaos analysis developed in the natural sciences require very fine levels of disaggregate analysis. However, typical social science data sets lack the necessary detail at all levels of the phenomenon under study.

In spite of these limitations, however, Dendrinos argues that the mathematically-based chaos theory approach is not without merit for social investigation (p. 242):

To conclude, however, that social science ought to downplay mathematical chaos theory and its insights, and instead persist in learning from only static, sharp, or stable dynamical models would be erroneous, and even perni-

cious. It would deprive the analyst of an ability to obtain intuitively appealing qualitative insights, simply because one lacks the comfort of very many and accurate measurements. Such luxury may never be afforded the social scientist, while the social agent is always confronted with a need to act. The agent will always be either right or wrong in its speculative action; consequently, the agent will be either rewarded or penalized. A mathematical chaos-ignorant social scientist would not be an effective or desirable advisor to the social agent.

4.3.2 Systems Theory

When a social scientist is first exposed to complexity theory, he or she is immediately reminded of the body of research and practice generally known as *systems theory*. As defined above, complexity can only emerge in the context of a system. The characteristics of complex dynamics, including feedback loops and reciprocal causality, recall the input and output diagrams of systems theorists and the circular causality described in family therapy. Under the heading "New Jargon or New Insights?" M. Ward (1995) provides a concise summary of the similarities and differences between the two approaches (p. 635):

> *Although their terminology differs, chaos and family systems theory explore similar themes. According to Laszlo (1972[8]), natural systems, including families, have four characteristics. First, they are ordered wholes, operating under the constraint of fixed forces. Second, they are able to stabilize themselves through negative feedback to maintain a homeostasis. Third, through positive feedback, they are capable of morphogenesis and adaptive self-organization. Finally, natural systems tend to evolve an increasingly hierarchical structure, whereby a system at one level is a sub-system or supra-system at another. The fixed forces of family theory, homeostasis and morphogenesis, become parameters, attractors, and bifurcations for chaologists.*
>
> *In spite of their surface similarities, chaos theory is able to answer two criticisms aimed at family systems theory: limitations arising from the con-*

[8] Laszlo, E (1972) Introduction to systems philosophy: Toward a new paradigm of contemporary thought. New York: Gordon & Breach.

cept of circularity and a failure to show the relationship between order and disorder.

The latter point is clarified further in an article by Keith Warren and colleagues. (1998, pp. 364-365):

> *Another difference between complexity theory and the traditional systems approach . . . lies in the way in which the two see the outcome of the development of a system. Traditional systems theory suggests that systems or social organizations are quite orderly, rational, and stable. [. . .] Complexity theorists, on the other hand, see systems as constantly changing because nonlinear processes tend to build on themselves and thus cause change from within.*

What we see here is a confluence of ideas developed over the last several decades independently from each other, with broad areas of agreement regarding the existence and structure of systems and their fundamental role in determining natural and social events. Complexity theory provides a meaningful extension of systems theory in that it offers an explanation for change and evolution within a systems context. The renowned systems theorist Niklas Luhmann (1994) is an important example of such an influence, his work incorporating the concept of autopoesis from chaos research in biology conducted by Humberto Maturana and Francisco Varela (1982)[9]. In general, it should not be surprising that there are important overlaps in complexity and systems approaches, given that General Systems Theory—the starting point for much of systems thinking—was developed by Ludwig von Bertalanffy (1968) (among others) in order to provide general principles which could be used in such diverse disciplines as psychology, biology, and sociology. Keith Warren and colleagues (1998) note that the term "organized complexity" already appeared twice in the above cited standard work of von Bertalanffy, but (p. 364) "whereas Bertalanffy tended to look at the overall outlines of developed systems, contemporary complexity theories often focus on the way in which the local interactions of individual actors give rise to a global system and the ways in which those local interactions act to maintain and increase the complexity of the system. They are interested in the evolution of complex systems."

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[9] The reader is referred to the insightful discussion by Klaus Kießling (1998) regarding Luhmann's adaptation of the concept autopoesis to his work, and how this concept has been developed over time.

4.3.3 Multilevel Analysis

Multilevel analysis is, as the name implies, a form of hierarchical data analysis taking into account several "layers" of causal factors. More conventional social science approaches tend to focus either on characteristics of individuals (e.g., gender, age, specific behaviors or beliefs), or on characteristics of a population (e.g., the prevalence of poverty, unemployment, or disease). In terms of investigating causal factors for social and health problems, both approaches have been criticized. The former is accused of the *individualistic fallacy* (see above), ignoring dynamics and processes which are greater than specific individuals and thus can not be measured adequately at that level. The latter approach can result in the *ecological fallacy*, in which associations at the population level are used to make statements of causality at the individual level[10].

Social epidemiology has shown an increased interest in multilevel analysis as a way to address both critiques. Through multilevel models, the disease outcome of interest can be analyzed statistically as being the result of *both* individual *and* population-based characteristics. In so doing, new causal pathways can be explored. Norman B. Anderson (1998) describes, for example, *parallel causation* and *convergent causation*. In parallel causation (p. 567), "each level of analysis may contain risk factors for a single health outcome or pathogenic process. Each of these risk factors may be sufficient, but not necessary, for the prediction of outcomes or processes." Convergent causation is when (p. 568) "a convergence or interaction of variables from at least two levels of analysis lead to a health outcome or pathogenic process. Thus, variables within a single level may be necessary, but not sufficient, to produce an outcome. Here, factors from one level of analysis affect factors at another level, and this cross-level causation ultimately influences outcomes."

One example of such an analysis is reported by Ana V. Diez-Roux, et al. (1997). In this study, a multilevel analysis was conducted using US census data to determine if socioeconomic neighborhood characteristics are related to coronary heart disease (CHD), either directly, or by exerting influence on major risk factors (e.g.,

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[10] A classic example of the ecological fallacy is comparing meat consumption and rates of heart disease across countries. Although greater rates of heart disease may be significantly associated with greater meat consumption at the population level, this does not mean that cases of heart disease are caused by meat eating. Without information about the eating habits and disease status of specific subjects, the association at the individual level has neither been strengthened nor weakened.

blood pressure, smoking, and systolic blood pressure). The authors summarize their results as follows (pp. 53ff):

> *Our study suggests that neighborhood context may be important in shaping the distribution of CHD prevalence and risk factors, independent of individual-level variables. With some exceptions . . . living in more disadvantaged neighborhoods was associated with increased odds of smoking, increased systolic pressure, and increased serum cholesterol after adjustment for individual-level indicators. [. . .] Our study suggests that neighborhood social context may be among the many factors linking social structure to CHD. From a more pragmatic perspective, neighborhood measures were found to provide information on the socioeconomic environment that is not captured by similar indicators measured at the individual level. Both neighborhood and individual-level social class indicators appear to be important in shaping cardiovascular risk.*

In a multilevel analysis conducted by Patricia O'Campo, et al. (1995) on domestic violence, we see not only the association between the incidence of violence and socioeconomic indicators at the neighborhood level, but also how the inclusion of this level relativizes the effects of individual-level factors on the outcome. In this article, the results of an analysis including only individual-level factors (age, employment, marital status, education, etc.) is compared with a two-level model including the neighborhood features. As the authors state (p. 1095):

> *We focus here on comparing the results from the individual-level model with those from the two-level generalized estimating equation model. Many of the odds ratios for individual-level factors changed with the addition of neighborhood-level factors in the model. The effects of the individual-level variables on the risk of partner-perpetrated violence, with the exception of race, were diminished with the addition of the neighborhood-level variables. For example, when the neighborhood-level variables were added to the model, the protective effect of age was reduced by 21%. Similarly, the risk associated with increasing education was reduced by 32%. The risk associated with having a partner who used drugs was reduced substantially by 41%. The most dramatic change occurred with the race variable. With the addition of the*

neighborhood variables, the risk associated with being White changed from a non-significant risk to a statistically significant odds ratio greater than nine.

The authors conclude (p. 1096):

Including neighborhood-level information substantially improved the explanatory model for partner-perpetrated risk, as evidenced by the statistically significant relationships of the contextual [neighborhood] variables in the mixed model. Three of the four neighborhood-level factors—ratio of home owners to renters, high per capita income, and unemployment rate—were significantly associated with risk of partner-perpetrated violence in the generalized estimating equation two-level model. All of the significant neighborhood-level factors were indicators of social class.

As this brief description suggests, multilevel analysis is a source for complexity theory to the extent that it provides important evidence for the existence of multiple levels of causality in relation to a particular phenomenon.

4.3.4 The Transdisciplinary Approach

The transdisciplinary approach is closely related to multilevel analysis. At the root of each is the thesis that social and health-related phenomena can best be described when all levels of the phenomena are taken into account. Multilevel analysis has up to this point primarily sought to join two levels, the individual with the collective, in examining the causes of specific health outcomes. The transdisciplinary approach ambitiously seeks to provide a unifying basis for collecting and interpreting *all* data related to a particular phenomenon from *all* levels in order to produce more comprehensive explanatory models. Such an enterprise necessarily entails a more integrated and intensive collaboration between all the various disciplines generating knowledge regarding a particular problem. Such a collaboration is needed in order to produce an explanation which exceeds the capabilities of any one of the disciplines, hence the name *transdisciplinary*. Glenn Albrecht and colleagues (1998) trace the development of transdisciplinary thinking in the health sciences, presenting complexity theory as the theoretical basis for a further development of this approach. Here we consider a general description of what the transdisciplinary approach proposes.

Norman B. Anderson (1998) presents risk factors for disease as being dispersed over five primary levels: social/environmental, behavioral/psychological, organ systems, cellular, and molecular. The social/environmental aspects of human health have been the domain of the social and behavioral sciences; whereas, the latter three levels have been the focus of biomedical research. Anderson describes how social and behavioral factors have been shown to exercise an influence on all levels of the body, including the expression of genetic traits. He, therefore, argues for a closer cooperation between disciplines so that the connections between the various levels can be explored further. Anderson states that a primary barrier to such a collaboration is the growing complexity as the number of intervening levels increases. He sees relating information between adjacent levels as being the most feasible task (e.g., between the social/environmental and the behavioral/psychological or between the cellular and the molecular). In light of this problem, Anderson quotes the neuroscientists Churchland and Sejenowski who propose a "chain of models" being the result of such a collaboration (Anderson 1998, p. 569):

> *The ultimate goal of a unified account does not require that it be a single model that spans all levels of organization. Instead, the integration will probably consist of a chain of models linking adjacent levels. When one level is explained in terms of a lower level, this does not mean that the higher level theory is useless or that high-level phenomena no longer exist. On the contrary, explanations will coexist at all levels . . . .*

For Glenn Albrecht, et al. (1998) such an approach is not sufficient. They provide an overview of the various forms which disciplinary research can take (see Figures 6). According to their description, Anderson's proposal would be categorized as *multidisciplinary* or, at best *interdisciplinary*, as there is an information exchange between the various disciplines, but not necessarily a common conceptual basis. Albrecht and colleagues argue that, without a common problem definition and a common conceptual framework, applying the insights of the various disciplines to solve health problems fails because there is no means of integrating such a diversity of knowledge. In transdisciplinary work, it is the problem itself, and not the disciplines, which should define the field. Therefore, (p. 57) "our aim as transdisciplinary thinkers is to create a meta-theory which weaves this multiplicity of perspectives into a coherent whole whereby the differences in approach are complementary rather than contradictory." The various disciplines can be thought of as different ways of knowing which feed into integrated conceptual frameworks which in turn are fed through "transdisciplinary thinking" to produce a common conceptual framework or meta-theory for the particular problem under study (see Figure 7). The basis of this "trans-disciplinary thinking" is complexity theory, described by the authors as being a "non-disciplinary" framework which enables the process of transdisciplinary collaboration to develop. Concretely, the authors propose two possible strategies for implementing a transdisciplinary approach: (1) "associational" thinking across disciplines and (2) teamwork (p. 60):

> *The first approach involves an individual researcher examining findings from a multitude of disciplines. Using findings from single and interdisciplinary collaborations as a point of departure, the researcher transcends disciplinary boundaries by linking the disparate analyses together into a coherent framework. In some cases this involves thinking "associationally" rather than in a narrow and reductionistic fashion.*
>
> *The second approach involves the collaboration of team members with backgrounds in different disciplines. Disciplinary boundaries are blurred as researchers work co-operatively to bring together into some unified framework the diverse elements of a total explanation, including the objective and subjective, the reductionistic and holistic and so on. Under some circumstances, the effect of team members focusing on a particular problem is the creation of a common conceptual framework out of what were formally disparate analyses. Under a shared conceptual framework, discipline boundaries disappear altogether or are "transcended" and a new or "transdisciplinary" way of explaining a problem is created.*

Albrecht and colleagues provide several examples of transdisciplinary work. One is their aforementioned study on coronary heart disease prevention in coal mining communities in Australia. As the above description implies, epidemiological, socio-political, historical and behavioral perspectives were combined to describe the development of opposing world views which also affect responses to community-based prevention campaigns. A further example is the work of Stephen Kunitz (1994) in analyzing the effects of disease in the destruction of indigenous populations in South America. Kunitz synthesizes findings from history, geography, ecology, demography, nutrition, political economy, anthropology, epidemiology, immunology, and social psychology to explain the plight of native peoples related to the spread of disease. The result (Albrecht et al. 1998, p. 62):

> *Kuntz' analysis is truly transdisciplinary; he has sought to fully explore all facets of the problem by transcending traditional disciplinary boundaries and allowing "the problem define the field." His analysis works within two common conceptual frameworks, "domination" and "adaptation," operating as a dialectical process. Kunitz observes that socio-political domination accompanied the introduction of epidemic disease and facilitated cultural domination in the form of destruction of traditional customs and institutions and also exacerbated psychological collapse from stress and demoralization arising out of the colonization process. "Domination" is the structural process colonial governments imposed, while "adaptation" explains the dynamic processes occurring at the local level in response to continual change. In analyzing the economic, socio-political, cultural, physiological, psychological, genetic and ecological adaptation of various groups to the colonizing experience, Kunitz reveals how a web of causal factors has resulted in such a diversity of outcomes that attempts by any one discipline to explain the connections seem doomed to failure.*

The transdisciplinary approach, particularly as defined by Albrecht and colleagues, is an important source for complexity theory in that it describes the type of collaboration which must occur between disciplines so as to move toward a more integrated view of complex phenomena. The transdisciplinary approach also suggests what form complex explanations of such phenomena can take.

4.3.5 Social Simulation

Since the creation of the first computers, both the scientific and popular imagination have been captured by the idea of creating machines which can think and act as human beings, in other words, *artificial intelligence* (AI). This task has proved to be far more daunting than was earlier believed. As the speed and capacity of computers has improved there has, however, been considerable progress made in the field of *artificial life*; that is, creating programs which can not only function successfully under an array of circumstances independent of outside control, but which also demonstrate the ability to create new patterns and "adapt" to changing stimuli. No one would argue that such programs are the same as life, but their ability to imitate life by simulating known physical and social processes has created new opportunities for exploring the natural and social environment.

As Paul Cilliers (1998) describes, at the heart of the artificial intelligence debate is the discussion about what constitutes *intelligence*. There are those who argue that only a "weak" form of AI is possible. Such theorists and researchers draw attention to the fact that computers, however sophisticated, function according to set rules. Such a rule-based way of operating, although appropriate in response to specific stimuli, will never produce a truly intelligent machine, because the machine does not *understand* what it is doing and is therefore incapable of *intention*. That is, the computer lacks the central qualities associated with *thinking*. Cilliers agrees that rule-based systems are limited, defending the idea of *connectionism* in the form of *neural networks* as an alternative. Neural networks refer to the interconnected groups of nerve cells in the brain and how they are believed to function. Cilliers proposes that such networks constitute complex phenomena, as defined earlier. The complex dynamic within the networks generates *meaning* and thus *thought*. The way to a "strong" from of AI, that is one deserving of the name "intelligence," would be using complexity theory, modeled on the neural network, as a way of understanding intelligence. Thus, a set of rules would no longer be the foundation, but rather an interconnectedness which would exhibit all the qualities of a complex phenomenon and thus be able to reflect more directly how the brain functions. Of course, Cilliers does not have an answer to the concrete implications of such a model for the development of computers. The aim of his book is, rather, to argue for a philosophical shift so as to permit further progress in the field.

Parallel to the philosophical debate about the future of AI there is ongoing research in developing software to imitate natural and social processes. In terms of public health issues, the most interesting area of this research is the relatively new field of *social simulation*. This field is concerned with developing software and applications to be used in modeling a range of complex phenomena. Approaches include, for example, queuing models, multilevel simulations, cellular automata, and multi-agent models (see overview in Gilbert & Troitzsch 1999). This work has directly arisen from the discourse on complexity, social scientists having come together to develop new techniques which more closely reflect the complex dynamics of the problems which they study. In the words of Jonathan M. Epstein and Robert Axtell, two pioneers in the field and authors of the provocatively titled book *Growing Artificial Societies—Social Sciences from the Bottom Up* (1996, p. 19)[11]:

> *The broad aim of this research is to* ***begin the development of a more unified social science, one that embeds evolutionary processes in a computational environment that simulates demographics, the transmission of culture, conflict, economics, disease, the emergence of groups, and agent co-adaptations with an environment, all from the bottom up****. Artificial society-type models may change the way we think about explanation in the social sciences*

At another place in the same work, Epstein and Axtell describe the core methodological problems in social science which they are trying to address. Their description is quoted here in full because it so apply states a fundamental motivation for using social simulation as a tool (p. 1):

> *Herbert Simon is fond of arguing that the social sciences are, in fact, the hard sciences. For one, many crucially important social processes are complex. They are not neatly decomposable into separate sub-processes—economic, demographic, cultural, spatial—whose isolated analysis can be aggregated to give an adequate analysis of the social process as a whole. And yet, this is exactly how social science is organized, into more or less insular departments and journals of economics, demography, political science, and so forth. Of course, most social scientists would readily agree that these divisions are artificial. But, they would argue, there is no natural methodology for studying these processes together, as they co-evolve.*
>
> *The social sciences are also hard because certain kinds of controlled experimentation are hard. In particular, it is difficult to test hypotheses concerning the relationship of individual behaviors to macroscopic regularities, hypotheses of the form: If individuals behave in thus and such a way—that is, follow certain specific rules—then society as a whole will exhibit some particular property. How does the heterogeneous micro-world of individual behaviors generate the global macroscopic regularities of the society?*
>
> *Another fundamental concern of most social scientists is that the rational actor—a perfectly informed individual with infinite computing capacity*

[11] Emphasis in original.

who maximizes a fixed (non-evolving) exogenous utility function—bears little relation to a human being. Yet, there has been no natural methodology for relaxing these assumptions about the individual.

Relatedly, it is standard practice in the social sciences to suppress real-world agent heterogeneity in model-building. This is done either explicitly, as in agency models in macroeconomics, or implicitly, as when highly aggregate models are used to represent social processes. While such models can offer powerful insight, they "filter out" all consequences of heterogeneity. Few social scientists would deny that these consequences can be crucially important, but there has been no natural methodology for systematically studying highly heterogeneous populations.

Finally, it is fair to say that, by and large, social science . . . has been preoccupied with static equilibria, and has essentially ignored time dynamics. Again, while granting the point, many social scientists would claim that there has been no natural methodology for studying non-equilibrium dynamics in social systems.

According to Epstein, Axtell, and others, social simulation provides a new methodology which promises to address the issues above. In the computer environment one is able to set up artificial worlds populated by simulated social agents. The agents interact in complex ways, producing dynamics which can be observed and measured over time and at several levels. Experiments can also be conducted on this world by changing a broad range of parameters, depending on the nature of the world created. As the title of Epstein and Axtell's book implies, social phenomena can thus be "grown" and hypotheses systematically tested over the time span of the world's evolutionary process.

Timothy A. Kohler (2000) affirms the social simulation approach which he calls *generative social science* (p. 8)[12]:

Social science *is not primarily concerned with the behavior of isolated individuals. The critical questions are often of genesis of patterns and of processes: How do cooperative relations among unrelated individuals emerge and become stable? How do social institutions, norms, and values evolve? Or, we may be interested in questions that cannot be answered adequately*

[12] Emphasis in original.

without asking questions of genesis: Why are some kinds of organizations common and others rare? Agent-based modeling holds out the promise of "growing" social phenomena as a way of understanding them.

Kohler points out the limits of conventional social science in its focus on measuring specific variables and looking for statistical relationships between them. As he argues, a fundamental problem is identifying variables at a given moment in time and sorting them into the categories of "causes" and "effects," thus failing to recognize complex patterns of interaction which change over time (p. 9)[13]:

> *What is the danger, you might say, of reifying these variables and pretending that one causes the other, so long as we understand that this is just a convenient shorthand for something that we would all agree to? The problem is the likelihood that there are* ***evolving co-adaptational interactions*** *among the agents (and between the agents and their environments) in such settings, whereas the analysis of static variables as effective contexts for decisions assumes a fixed relationship among the agents and their environment.*

Kohler argues that social science needs to focus on how systems change over time, which includes changing relationships among the various levels of the phenomena and thus among the various variables themselves. This process of change is characterized by evolution and adaptation to changing circumstances. Thus, Kohler's primary critique of conventional models is their assumptions about causality (p. 10):

> *Agent-based modeling is a way (the most practical and thorough way I can see) for studying systems that are characterized by many co-evolutionary interactions. Co-evolutionary systems defy analysis in terms of traditional one-way cause-and-effect, and we are still searching, I think, for satisfactory replacements for these concepts that will allow us to compare change in different systems and allow us to answer "why?" questions of perceived patterns.*

A second critique which Kohler wages at conventional approaches to social science is the inability to model *hierarchies of emergence* and *circumstance* (context). The former refers to the layered connections which develop over time among variables related to a particular social phenomenon. Typical analyses are descriptive only, providing neither insight into the dynamic processes which led to such connections nor to the structures of interaction which are emerging. The reference to cir-

[13] Emphasis in original.

cumstance refers to how the structure of a phenomenon can depend on the particular situation or context in which it is expressed, without any change in the underlying mechanisms. To illustrate the latter, Kohler quotes an example used by Charlotte Hemelrijk based on the work of the ethnologist Hinde (Kohler, p. 10):

> *Hinde distinguished four different levels of complexity, each with its own emergent properties: individual behavior, interactions, relationships, and social structure. Each level is described in terms of the level below it, and levels influence each other mutually. For instance, the nature of the participants' behavior influences their relationships, but these relationships also in turn affect the participants' behavior. A caution that follows from this view is that observed social structure can vary dramatically with circumstances, without any changes in the underlying motivational mechanisms or strategies.*

For Kohler the solution to this problem lies in moving beyond static descriptions to generating dynamic models (through simulation) which can demonstrate possible causal pathways for the development of a phenomenon. As he remarks laconically (p. 11): "It is one thing to describe the structure of a house as seen from the street; it is quite another thing to build one."

The final criticism of conventional social science discussed by Kohler is the tendency to begin (and end) analysis toward the upper end of the structural hierarchy of the phenomenon. What he means is that descriptive models usually present the phenomenon of interest as being the product of a current constellation of several variables. In the interest of providing a most accurate description of the phenomenon, such models can be elaborate, taking into account a host of factors at several different levels. Kohler proposes that a dynamic view of a phenomenon could result in more parsimonious models offering clearer insights into underlying mechanisms. Given that complex phenomena begin small and evolve more complex structures over time, one could conceivably identify a few key parameters which could be demonstrated to generate the current phenomenon in its various aspects. Thus, through experimentation at a lower level in the structural hierarchy, the phenomenon could be re-created, thereby providing valuable insights into the dynamics of the phenomenon and potential for intervention. The conventional approach stays at the current level of complexity and thus is unable to move beyond description of the current state and speculations about its genesis.

In direct reference to the debate in the field of artificial intelligence as a whole, Kohler clarifies that the methods currently under development represent "weak" forms of social simulation. The "real" world is not being re-created; the artificial societies generated are, however, useful models which reflect social processes to a degree no other method has achieved to date (pp. 3, 4):

> *The claim of "weak social simulation" is simply that artificial societies are useful because without using the power of a computer and appropriate software the processes in question could not be studied effectively. This is because the systems of interest are composed of many agents interacting not only with each other but also with a possibly dynamic environment according to rule sets that may be complicated and may change over time. These problems are analytically intractable and, when studied through simulation, results often cannot be predicted with great accuracy even by the programmer. Nevertheless, these are only toy worlds. [. . .] The claim of weak social simulation, then, is emphatically not that the simulated processes as a whole constitute living societies within a computer that can be studied from any angle desired. These are not societies composed of individuals exhibiting common sense, who could learn, develop skills, classify, and generalize according to situationally appropriate criteria, imagine, and plan.*

Reflecting the argument of Paul Cilliers, Kohler does not, however, rule out the possibility of "strong" social simulation, and points to evolutionary psychology, among other fields, as offering ideas to promote development in this direction.

The contribution of social simulation to complexity theory is, thus, an important one. The emerging techniques provide new tools for the social sciences specifically developed to investigate complex dynamics. An example of how simulation can be used as part of the model-building process will be presented in Chapter 5.

4.3.6 Dietrich Dörner and *Strategisches Denken*

Dietrich Dörner (1989) provides a unique contribution to complexity theory. Dörner is not so much interested in complex phenomena per se (these are taken as a given), but rather in typical human reactions to complex situations. On the basis of several studies carried out by himself and colleagues, he argues that it is not the complexity of the situations themselves which lead to failure when people try to intervene, but rather the human tendency to misjudge such situations and thus to act in counter-productive ways. Dörner's work is of particular importance because of its implications for the design of interventions to influence complex problems typical in public health and other fields. Essentially, he lays the groundwork for *complex problem solving*.

Dörner's research has consisted of creating a variety of computer simulations of complex situations on which subjects are asked to exert influence in order to produce the best possible outcomes. For example, a fictitious town named Lohhausen was created. The subjects were given control over certain parameters affecting the social and economic well-being of the town, and their success over a simulated period of ten years was charted. Examples of other simulations include: the ecology of a fictitious East-African region, firefighting in a forested area, and temperature control of a cold storage system. In each case, the state of the complex system is reflected by computer generated values of primary indicator variables. The subjects' problem-solving behavior, which is the focus of the study, is monitored in various ways in order to track information-seeking, criteria for decision-making, causal beliefs about the simulated situation, etc. The results of these various studies, as summarized in *Die Logik des Misslingens – strategisches Denken in komplexen Situationen* (Dörner 1989), will be presented here.

As Dörner describes, the world we live in has become increasingly complex. We are challenged by this complexity to develop new approaches to problem solving which go beyond our typical way of functioning (p. 13):

> *In einer Welt von interagierenden Teilsystemen muss man in interagierenden Teilsystemen denken, wenn man Erfolg haben will. (. . .) Allem Anschein nach ist aber die „Mechanik" des menschlichen Denkens in der Evolution einmal „erfunden" worden, um Probleme „ad hoc" zu bewältigen. Es ging um das Feuerholz für den nächsten Winter. Es ging um einen Plan, wie man eine Pferdeherde so treiben könnte, dass sie in eine Schlucht stürzte. Es ging um den Bau von Fallen für ein Mammut. Alle diese Probleme waren „ad hoc" und hatten meist keine über sich selbst hinausgehende Bedeutung. Der Bedarf an Feuerholz für eine Steinzeithorde unserer Vorfahren gefährdete nicht den Wald, genauso wenig wie ihre Jagdaktivitäten den Wildbestand gefährdeten.*

This *ad hoc approach* to problem-solving has several drawbacks when applied to complex situations, including:

- Taking action before adequately analyzing the problem situation ("actionism")
- Ignoring long-term effects and side effects of actions
- Ignoring the process of how the problem developed, focusing on the current state only
- Formalizing problem-solving into specific methods which are generalized to a variety of situations ("methodism")
- Creating tools to solve the problem instead of concentrating resources on a more thorough problem analysis
- Developing a cynical attitude when a problem cannot be resolved by simple interventions

The primary feature exhibited by the subjects who were best able to address the simulated situations was a more complex way of thinking about the problem (p. 39):

> *Die „guten" Versuchspersonen handelten also gewissermaßen „komplexer". Sie berücksichtigten mit ihren Entscheidungen jeweils verschiedene Aspekte des gesamten Systems und nicht nur Einzelaspekte. Dies ist sicherlich ein Verhalten, welches generell bei komplizierten*[14]*, vernetzten Systemen angemessener ist als ein Verhalten, welches in isolierter Weise nur Einzelaspekte betrachtet.*

A central aspect of this more complex way of thinking is a focus on understanding the *process* of the problem situation, as opposed to focusing on the state of the phenomenon in the moment. By adopting a process orientation, one can avoid the common pitfall of trying to exert too much control over the current situation so as to produce an immediate positive result (p. 50)[15]:

> *Eine solche Tendenz zur Übersteuerung ist charakteristisch für den Umgang von Menschen mit dynamischen Systemen. Wir gehen nicht von der Entwicklung des Systems, also von den Zeit**differenzen** zwischen aufeinander folgenden Zeitpunkten aus, sondern von dem zum jeweiligen Zeitpunkt feststellbaren **Zustand**. Man reguliert den **Zustand** und nicht den **Prozess** und er-*

[14] Dörner does not differentiate between the words *komplex* and *kompliziert*, often using the terms interchangeably. The phenomena he describes do, however, meet the definition of complexity as presented in this paper.

reicht damit, dass das Eigenverhalten des Systems und die Steuerungseingriffe sich überlagern und die Steuerung überschiessend wird.

Dörner's general approach for planning appropriate interventions is not new, reflecting a typical problem-solving schema. Innovative is his integration of complexity theory into the planning process itself. Essentially, one needs to:

Recognize the Complexity

For Dörner this means, above all, to recognize the interconnectedness (*Vernetztheit*) of the various aspects of the problem (p. 61):

Ein Eingriff, der einen Teil des Systems betrifft oder betreffen soll, wirkt immer auch auf viele andere Teile des Systems. Dies wird „Vernetztheit" genannt. Vernetztheit bedeutet, dass die Beeinflussung einer Variable nicht isoliert bleibt, sonder Neben- und Fernwirkungen hat. Die Vielzahl der variablen Merkmale bringt es mit sich, dass man die Existenz solcher möglichen Neben- und Fernwirkungen leicht übersieht.

Focus on the Dynamics

In complex problem solving, the current state of the problem is not as important as the overall dynamic driving the problem's development. Therefore, describing the features of this development are primary (p. 63):

Die Eigendynamik von Systemen macht weiterhin die Erfassung ihrer Entwicklungstendenzen bedeutsam. Bei einem dynamischen Gebilde darf man sich nicht damit zufrieden geben zu erfassen, was der Fall ist. Die Analyse der augenblicklichen Gegebenheiten reicht keineswegs aus. Man muss zusätzlich versuchen herauszubekommen, wo das Ganze hinwill.

Accept the Limits in Knowledge

Complex situations are characterized by an inherent opaque quality (*Intransparenz*) which hinders being able to see the phenomenon clearly and in its entirety. Even when the problem can be well described, the dynamic nature of the situation results in a residual uncertainty which can never be eliminated.

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[15] The orginal emphasis placed on certain words in this quotation and others from Dörner has been maintained.

Focus on the Phenomenon's Structure

Dörner emphasizes the need to make a mental picture of the phenomenon, that is, to create a model, in the broadest sense of the word. Such models should not be snapshots of any given moment, but rather moving pictures which show the interrelationship between the variables and depict the process of their co-development. The *structure* of the phenomenon consists of the features which make up this process.

Dörner's image of the chess player makes clear the challenges presented to the person attempting to address a complex problem (p. 66):

> *Wenn wir dieses Kapitel anschaulich zusammenfassen wollen, so können wir sagen, dass ein Akteur in einer komplexen Handlungssituation einem Schachspieler gleicht, der mit einem Schachspiel spielen muss, welches sehr viele (etwa: einige Dutzend) Figuren aufweist, die mit Gummifäden aneinander hängen, so dass es ihm unmöglich ist, nur eine Figur zu bewegen. Außerdem bewegen sich seine und des Gegners Figuren auch von allein, nach Regeln, die er nicht genau kennt oder über die er falsche Annahmen hat. Und obendrein befindet sich ein Teil der eigenen und der fremden Figuren im Nebel und ist nicht oder nur ungenau zu erkennen.*

Dörner provides further insights into the pitfalls of complex problem solving. For example, there is a *tendency to focus on one goal* in planning, an approach too simple and therefore problematic (p. 78):

> *Es muss hier betont werden: man kann in komplexen Realitäten nicht nur* ***eine*** *Sache machen. Man kann daher auch nicht nur* ***ein*** *Ziel anstreben. Strebt man ein Ziel an, so kann es sein, dass man dadurch unversehens andere Missstände* ***erzeugt****, also neue Probleme schafft.*

It is also important to think in *causal networks*, rather than in causal chains, and to picture these networks existing in a *hierarchy of levels* (p. 113):

> *Nun ist es nicht nur wichtig, die kausalen Beziehungen zu kennen, die zwischen den einzelnen Variablen eines Systems herrschen. Darüber hinaus sind noch andere Wissensbestände notwendig oder nützlich: Es kann zum Beispiel wichtig sein zu wissen, in welchen Oberbegriffs-Unterbegriffshierarchien eine bestimmte Variable eingebettet ist. Und schließlich kann es wichtig sein,*

zu wissen, zu welcher Teil-Ganzes-Hierarchie eine bestimmte Variable gehört, von welcher „Ganzheit" sie ein Teil ist und aus welchen Teilen sie wiederum besteht.

In regard to thinking hierarchically Dörner warns, however, to concentrate on the scale (*Auflösung*) of the problem most relevant for the question at hand. (Just as we would use a camera with a zoom lens to provide a certain level of magnification to frame the subject according to our interests.) There are, theoretically, an endless series of levels which constitute a complex phenomenon. Identifying and conceptualizing the levels most useful for intervention is an important part of achieving success. As part of this process he recommends identifying *critical variables* and *indicator variables*. Critical variables are those which are connected with many others in the system and therefore offer potential leverage for influencing a host of other variables and, ultimately, the system as a whole. Indicator variables are those which are dependent on many other variables but which, themselves, do not exert major influence on the system. Indicator variables can be used for tracking the state of the system over time.

Another potential pitfall is what Dörner calls the *reductionist hypothesis*. That is, the complex problem is made simpler by naming one variable as the key to the problem's developmental process. The resulting model of the problem is centrally organized around this one variable, thereby ignoring the inherent interconnectedness between variables in complex systems.

In attempting to picture the future course of a dynamic situation, we also typically assume that *the future is a linear continuation of the present*. This is actually another result of focusing on the present moment, as opposed to thinking in terms of process. A process-oriented approach is open to changes in trajectory and unexpected influences on the course of events; whereas, the focus on the present overvalues this moment in time and the relationships which currently exist among the several variables.

A further point with far-reaching consequences for strategic planning is the central role which *context* plays in whether an intervention is successful. Dörner strongly argues that appropriate decisions in response to complex problems cannot be generalized, but must be tailored directly to the situation at hand. Analogous thinking based on experience allows the comparison of different problem situations and is therefore useful in constructing models. However, such comparisons should not lead to generalized methods (pp. 139-140):

> *In einem komplexen, vielfach vernetzten System sind Abstraktionen, die zu solchen Dekonditionalisierungen von Verhaltensweisen führen, gefährlich. Kontextuelle Abhängigkeiten von Maßnahmen sind eher die Regel als die Ausnahme. Eine Maßnahme, die in der einen Situation richtig ist, braucht in der anderen Situation nicht richtig zu sein. Solche kontextuellen Abhängigkeiten bedeuten, dass es wenige allgemein (also bedingungsfreie) Regeln gibt, aufgrund deren man sein Handeln einrichten kann. Jede Situation muss neu bedacht werden.*

There are, therefore, *only local rules* to be discovered and observed. A complex problem is dynamic, constantly changing its form and expression. Therefore, a successful strategy is one which is constantly being adapted to the evolving situation (pp. 143-144):

> *Was Moltke[16] für das strategische Denken im Kriege vor Augen hatte, gilt wohl allgemein für den Umgang mit hochgradig interdependenten Systemen. Schematisierungen und Reglementierungen sind hier gefährlich. Das Handeln muss auf die jeweiligen Kontexte eingestellt werden und muss den sich wandelenden Kontexten immer wieder sich anpassen. Dies ist natürlich sehr schwierig, bei weitem schwieriger als der Umgang mit wenigen allgemeinen Handlungskonzepten. Man muss jeweils ein genaues Bild der sich ändernden Bedingungen behalten und darf nicht glauben, dass das Bild, welches man einmal von der Situation gewonnen hat, endgültig ist. Es bleibt alles im Fluss, und man hat sein Handeln auf die fließenden Bedingungen einzustellen. Diese Anforderung ist der menschlichen Tendenz zur Generalisierung und zur Bildung abstrakter Handlungsschemata in höchstem Maße entgegengesetzt. Wir haben hier ein Beispiel dafür, wie eine wichtige Form der menschlichen Geistestätigkeit zugleich schädlich und nützlich sein kann. Mit der Bildung abstrakter Konzepte muss man selbst „strategisch" verfahren. Man muss wissen, wann sie angebracht ist und wann nicht. (Es folgt daraus nicht, dass es* ***keine*** *Regeln in einer solchen Situation gibt; es gibt Regeln, aber diese haben immer nur lokale Bedeutung.)*

In light of this, it is useful to adopt the definition of "strategy" which Dörner quotes directly from the abovementioned war strategist (p. 143):

Die Strategie ist ein System der Aushilfen. Sie ist mehr als Wissenschaft, ist die Übertragung des Wissens auf das praktische Leben, die Fortbildung des ursprünglich leitenden Gedankens entsprechend den stets sich ändernden Verhältnissen, ist die Kunst des Handelns unter dem Druck der schwierigsten Bedingungen. (...) Für die Strategie können daher allgemeine Lehrsätze, aus ihnen abgeleiteten Regeln und auf diese aufgebaute Systeme unmöglich einen praktischen Wert haben.

It follows from this definition that Dörner is against detailed planning when it comes to addressing complex problems. He especially warns against mathematical formalisms which claim to provide a comprehensive overview of the situation; mathematical representations are useful in creating clarity in the description of relationships, but should not become formulas on which intervention decisions are based. Also, Dörner advocates for decisions to be delegated to lower levels on an organizational hierarchy so as to best allow the most immediate and adaptive response to the local situation (p. 245):

In sehr komplexen und sich schnell verändernden Situationen ist es wohl vernünftig, nur in groben Zügen zu planen und möglichst viele Entscheidungen nach „unten" zu delegieren. Dies setzt viel Selbständigkeit und Vertrautheit mit der „Generallinie" bei den ausführenden Stellen voraus. Man braucht in solchen Situationen das, was Malik „Redundanz potentieller Lenkung" nennt, also viele Beteiligte, die alle Leitungsaufgaben im Sinne der Generaldirektiven übernehmen können.

This approach is contrasted with the aforementioned "methodism"; that is, routinely applying certain intervention sequences which have proved to work in the past. Each complex situation is unique, even though it may bear resemblance to previously encountered situations. Attention must therefore not be focused on some typology of factors believed to be characteristic for a certain type of problem, but rather on discerning the specific configuration of factors in the concrete situation and discovering the unique dynamic which is operative (p. 257):

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[16] Helmuth (Carl Bernhard) Graf von Moltke (1800-1891) was a general and a celebrated war strategist in the Prussian Empire.

In vielen komplexen Situationen kommt es nicht nur darauf an, wenige „charakteristische" Merkmale der Situation zu betrachten und sich gemäß dieser Merkmale zu bestimmten Aktionen zu entschließen, vielmehr kommt es darauf an, dass man die jeweils ganz spezifische, „individuelle" Konfiguration der Merkmale betrachtet, der jeweils auch nur eine ganz individuelle Sequenz von Aktionen angemessen ist. Der jeweiligen individuellen Konfiguration wird der „Methodist" nicht gerecht. Denn er hat seine zwei, drei Verfahren, und die werden nach Maßgabe allgemeiner Merkmale der Gesamtsituation angewendet. Die Individualität der Situation, die ihrer spezifischen Merkmalskonfiguration liegt, bleibt unberücksichtigt.

Dörner concludes by stating that complex problem solving cannot be reduced to one idea or to a specific set of skills; it is, rather the ability to approach a variety of situations appropriately by being open to the dynamics of complexity. He believes that computer simulations of complex problems provides the ideal training ground to help people learn these kind of skills (p. 309):

Es kommt nicht darauf an, einen bestimmten „Denkstil" zu fördern. Ich hoffe, hinlänglich klar gemacht zu haben, dass man das, was oftmals pauschal „vernetztes Denken" oder „systemisches Denken" genannt wird, nicht als eine Einheit, als eine bestimmte, isolierte Fähigkeit betrachten kann. Es ist ein Bündel von Fähigkeiten, und im wesentlichen ist es die Fähigkeit, sein ganz normales Denken, seinen „gesunden Menschenverstand" auf die Umstände der jeweiligen Situation einzustellen. Die Umstände sind immer verschieden! Mal ist dieses wichtig, mal jenes. Es kommt darauf an! Den Umgang aber mit verschiedenen Situationen, die verschiedene Anforderungen an uns stellen, kann man lernen.

4.3.7 Other Sources

In addition to the above, there are several other sources feeding into the development of complexity theory. Some of these will be described here briefly.

Game Theory

The French mathematician Émile Borel was the first to explore games of chance and theories of play from a research perspective. The Hungarian-American mathematician John von Neumann is generally credited for establishing the mathematical basis for all further developments in the field through his work early last century. In general, *game theory* explores various social phenomena on the basis of models representing contests between one or more players (persons or entities). The players behave according to certain rules so that, at any one point, all available options for each player and for the contest as a whole can be mathematically described. The "games" which serve as models can reflect popular parlor games (like chess or poker); however, more commonly employed are formalized versions of such games which have been given specific names (e.g., Prisoner's Dilemma or Chicken). The basic principle of modeling interactive phenomena on the basis of rule-based action on the part of two or more agents lies at the heart of current developments in social simulation. Game theory thus serves as a theoretical and empirical source of information for modeling complex behavior. (see Eidelson 1997)

Behavioral Complexity Theory

Prior to the discussion of chaos theory in the natural sciences spurring interest in complex phenomena in the social sciences, a theory was being developed to describe complex dynamics at the level of human behavior: *behavioral complexity theory*. Although developed independently from the complexity discourse, behavioral complexity theory essentially applies primary ideas of complexity theory as described here—what Streufert and Satish (1997) call *science-wide complexity theory*—to human psychology. As Streufert and Satish write (p. 2096): "Streufert has discussed the confluence of science-wide and behavioral complexity theory. Even though the former attempts to find common processes in all the sciences and the latter theory has, to date, limited itself to human behavior, there are many similarities in approach and in explanations of observed phenomena. Differences between the two theories are minor in comparison to their commonalities." The fact that behavioral complexity theory proposes similar dynamics as general complexity theory is a further validation of the relevance of complexity theory for the social sciences. Behavioral complexity theory also offers specific concepts which can assist in applying general complexity theory to the examination of psychological phenomena.

Postmodernism

To what degree postmodernism contributes to the complexity discourse is controversial. This is likely due to the fact that postmodern thought inherently rejects ideologies and formalisms, which means that "postmodernism" does not represent a specific theory or school but rather stands for a broad critique of modernism on the part of a diverse group of philosophers, artists, researchers, etc. On the one hand there are authors such as Paul Cilliers (1998) who in his book entitled *Complexity and Postmodernism: Understanding Complex Systems* argues that complexity theory can be a basis for scientific theory and practice which takes seriously the postmodern critique. According to this critique, scientific knowledge is in a crisis characterized by a growing skepticism in society regarding scientific claims of truth, objectivity, and authoritative knowledge. Cilliers sees complexity theory as promoting a new understanding of what science is (p. 129-130) (cf. Perna & Masterpasqua 1997):

> *We now possess a framework for developing a "narrative" interpretation of scientific knowledge. Instead of being denotative, external, self-centered, logical and historically cumulative, scientific knowledge is produced through interaction and diversity, and has become more and more embedded within the context of the wider social network. Science, as well, can only survive by entering the agonistics of the network.*
>
> *The criteria for useful knowledge are no longer denotative, but more flexible. Because it forms part of an open system, it has to take the wider scenario into account. It cannot depend solely on the authority of either history, or the expert, to legitimate it. [. . .] The idea of narrative knowledge that is also scientific can now be summarized. The world we live in is complex. [. . .] Descriptions of it cannot be reduced to simple, coherent and universally valid discourses.*

On the other hand there are authors such as David Byrne (1998) who see complexity theory as an alternative to modernism which avoids the pitfalls inherent in the postmodern discourse. Byrne sees in postmodernism a tendency to relativism which negates the role of human agency in the process of social change (p. 45):

> *In the case of postmodernity we have to accept that the form of social action is absolute social inaction—the disengagement of the intellectual project from any commitment to any social program whatsoever—bone idleness promoted to metatheoretical program. [. . .] Complexity/chaos offers the possibility of an engaged science not founded in pride, in the assertion of an absolute knowledge as the basis for social programs, but rather in a humility*

about the complexity of the world coupled with a hopeful belief in the potential of human beings for doing something about it.

Evolutionary Theory

The concept of evolution, central to complexity theory, has its origins in the biological theory of species evolution. Central tenets of evolution have been so integrated into the natural sciences (including complexity theory) that evolutionary theory can best be viewed as a central scientific idea rather than a particular school of thought. Complexity theory arose partly as a result of attempts to answer fundamental questions regarding the forces driving evolutionary processes and the trajectories which evolution assumes. Over time, the discussion of evolution has expanded to include not only the evolution of single organisms or species, but to consider the co-evolution of various life forms in any given environment.

An important image from evolutionary theory used to describe complex dynamics is the *fitness landscape* (Eidelson 1997, p. 57):

> *Several investigators have found the concept of fitness landscapes useful in analyzing the adaptation and co-evolution of complex adaptive systems. In this metaphor, the agent is pictured as moving about on an imaginary topographical map. The landscape typically includes hills and valleys of varying degree, and the tallest peak represents the site of the agent's optimal fitness. Alternatively, the fitness landscape can be viewed upside-down; from this perspective, optimal fitness lies at the bottom of the deepest basin. In either case, it is important to note that not all agents climb identical landscapes, and that the landscape itself can change. In short, complex adaptive systems differ from each other in the paths and obstacles to optimization.*

And in the words of David Byrne (1998, p. 32):

> *The point about the landscape formulation is that it shows that where you start from is of great importance. It is much easier to go up a ridge to a local peak than to descend into a valley and ascend again towards a more remote and higher peak. Any fell walker will understand this immediately. Landscapes represent available options but can themselves be changed because evolution is not just a matter of change in single organisms but also reflects the impact of change in one organism on others—co-evolution. There is*

a clear association between the imager of fitness landscapes and the idea of far from equilibric time dependent systems.

Timothy A. Kohler (2000) highlights the contributions of *evolutionary psychology*, a field which seeks to explain psychological behavior in terms selective adaptation over millions of years. For Kohler, evolutionary psychology offers hope of being able to create “strong” computer simulations of social interactions. If one accepts the premise that current complex behavioral patterns emerged from less complex forms, one could create simulations on the basis of a few key parameters which would “evolve” into structures bearing significant similarities to “real” human society.

4.4 Conclusion

We began this chapter with a description and critique of the dominant scientific paradigm. It was shown how a positivist approach fails when attempting to describe dynamic social realities. Complexity theory was introduced as an alternative view which relies on both quantitative and qualitative sources of information to take into account several levels of causality evolving over time. Numerous sources of complexity thinking were drawn together to provide a comprehensive overview of this emergent perspective for the purpose of examining public health issues. Examples of disease etiology and prevention were provided as illustration. Each source of complexity theory provides a unique contribution to re-visioning public health from a complexity perspective.

Chaos theory offers a vocabularly to describe basic dynamics and structures; however, its origins in the natural sciences present considerable barriers for mathematical applications to social problems. *Systems theory* can be viewed as a forerunner of the current complexity discourse, having emphasized the dynamics of related elements. The complexity perspective challenges systems theory to give more attention to how systems evolve over time, often in unpredictable ways. *Multi-level analysis*, an increasingly common approach in social epidemiology, is a source for complexity theory to the extent that it provides important evidence for the existence of several levels of causality and their interrationship with regard to a particular health or disease phenomenon. The *transdisciplinary approach* describes the type of collaboration which must occur between disciplines so as to move toward a more integrated view of complex phenomena. This approach also suggests what form complex explanations of such phenomena can take. *Social simulation* is a new analytical tool for building and exploring multi-level models, thus providing new possibilities for conceptualizing social phenomena in a dynamic environment. Dietrich Dörner's *strategic thinking* provides a foundation for developing practical solutions to complex problems, and thus offers a framework for creating effective interventions in a public health enviroment. Finally, the contributions of *game theory*, *behavioral complexity theory*, *postmodernism*, and *evolutionary theory* were briefly summarized.

Taken together, the various sources of complexity theory are complementary. We see a confluence of similar ideas over the course of time and within several disparate disciplines. This chapter was an attempt to bring together the sources most relevant for public health applications, in this way providing a basis for further exploration of what a complexity perspective can mean when approaching issues of disease and health.