Contents

1
Models, Methodologies, and Metaphors on the Move[1]

Andreas Wimmer

The plan of the book

Most of our contemporaries would agree that we live in a time of rapid and deep-going change. Globalization, the end of certainty, and post-modernity are three prominent catch-words describing our current condition. Many are concerned about declining political steering capacities, run-away financial markets, global warming, the biotechnological and micro-electronic revolutions, to name just a few particularly prominent issues. While it is hard not to be impressed by the impact of these various processes unfolding before our eyes, we may be well advised to distrust our perceptions. After all, it belongs to the most salient, if not defining characteristics of modern societies that each generation witnesses a fundamental transformation and an upheaval unprecedented in dynamic and impact – a phenomenon that Fowles (1974) has aptly described as 'chronocentrism'.

Is it just another inescapable illusion to perceive a fundamental and unprecedented change in the way the sciences describe and understand phenomena of change? I believe there is enough ground to believe that we are not victims of a chronocentric distortion when making such a claim. All the major disciplines have moved – some earlier than others – beyond older teleological views, which saw change unfolding along a pre-defined path from stage to stage until it reached a known end point: homo sapiens sapiens, the modern society, a free market economy in equilibrium, etc. Today, processes rather than stages have moved to the centre of attention. Notions of equilibrium, reversibility, and determinacy have been displaced by disequilibria, irreversibility, and contingency (cf. Prigogine 1997).

This book reviews some of these innovations in the natural sciences, economics, and the social sciences. Six paradigms have been particularly influential in bringing about this pan-disciplinary paradigm shift: chaos theory and evolutionary theory in the natural sciences; path dependency and new institutionalism in economics; new modernization theory and neo-historical approaches in the social sciences. They all belong, as I will show in the following section, to a larger group of post-mechanistic models of change that share four fundamental properties. They contain elements of non-linearity: pathways of change depend on initial conditions, or a system may behave chaotically during certain periods. They are at least partially probabilistic and describe certain aspects or phases of change in a non-deterministic language. They foresee different possible trajectories of change and thus are multilinear in nature. And they postulate an irreversible process where past conditions determine possible changes in the future in a way that make a return to earlier states impossible.

Many of these paradigms and their core models have originated in one disciplinary field and then been applied to other areas of research, sometimes in a rigorous fashion, sometimes in more loosely metaphorical terms, thus 'migrating' across disciplinary boundaries. This volume discusses the experiences with such concept migration. It will not lead us, perhaps an unnecessary caveat, to a new meta-theory for explaining change, such as envisioned by the Gulbenkian Commission headed by Immanuel Wallerstein (1996). Nor are the editors inspired by what some have termed the 'Santa Fe *Zeitgeist*' that is, the search for common properties of all complex evolving systems (see the *Sante Fe lnstitute Studies in the Sciences of Complexity*, published by Addison-Wesley). We believe, as Reinhart Kössler will argue in more detail in his conclusion, that there are too many fundamental differences between natural and human systems to make this latest quest to find the hidden construction principles of the world more viable than its various predecessors.

More modestly and certainly less metaphysically inspired, we intend to document and at the same time foster the dialogue among members of a family of similar approaches. Rather than fusion or absorption into a metatheory, we believe that selective borrowing and mutual learning are the adequate strategies for improving our understandings of change in the various branches of the scientific enterprise. The book is planned accordingly. Each paradigm will be introduced by a scholar from the disciplinary field it originated from and then commented upon by representatives of the other disciplinary fields to which the paradigm has already been – or has the potential of being – applied to.

In this introduction, I should first like to briefly introduce the six paradigms and then offer a preliminary analysis of their commonalities and differences, including an admittedly speculative attempt at describing these in the language of stochastic matrices. The third section will explore the role of concept migration in more detail, offering a typology as well as a discussion of the difficulties and opportunities for innovation that the cross-disciplinary exchange of models, metaphors, and methodologies provides. The final section, to which the efficient reader may jump after having finished the first, will review the individual chapters. I begin with an overview of our six paradigms.

Chaos and order in climate change

Research on climate change addresses one of today's most pressing and broadly advertised issues, and perhaps represents one of the best funded and most transnationally integrated research enterprises. Beyond this obvious policy relevance, understanding climate change forms a specific intellectual challenge, both theoretical and empirical, given the sheer complexity and scale of the issues. This has posed formidable difficulties for modeling: Not only is it hardly possible to know all the relevant factors but also the integration of the various sub-processes into an overarching model poses difficulties, as the parameters proliferate in ever more complex equations. The fact that many sub-models contain important probabilistic elements does not make the task of explanation and prediction easier.

A climate system may have multiple stable states and therefore may respond to a temporary perturbation by moving to a new equilibrium – but it may also contain feedbacks that re-establish a equilibrium state. Chaos theory has proved to be an interesting tool to analyse complex patterns of change with non-linear properties such as for example bifurcations. Research on climate change thus offers an important starting point to question received notions of structure and change in a variety of scholarly fields. It is especially interesting for economists and social scientists because its object is large scale and complex and represents, as do societies and economies, an empirical entity that cannot be subjected to experimental manipulation.

Genetic variation in evolution

Evolution represents, since over a century, one of the major paradigms for studying change in the natural and social sciences. While the conceptual triad of variation, selection and inheritance (retention) has become commonplace since the days of Darwin, important features of evolutionary biology have been frequently overlooked. A striking example is the combination of chance and determinacy in evolutionary models, that has been somewhat obscured in what is called the modern synthesis of Darwinism stressing the gradual accumulation of mutations leading to the appearance of ever fitter species (cf. Gould 2002). This teleological perspective survives in fields that have borrowed evolutionary concepts from biology. Recent advances within the natural sciences, in particular biology, using up-to-date technology for research on the cellular and the molecular levels, but also in paleontology, once again have thrown the original features into sharp relief.

Perhaps the most exciting strand of this new research focuses on 'development', i.e. how genetic structures relate to phenotype, or more precisely, how genetic variation translates into shifts in phenotypical design. It turns out that 'chance' in the production of phenotypic variation is a much more patterned process than isotropically random. Genetic variation drifts non-deterministically along extended, phenotypically neutral pathways across genetic space until it 'hits' clearly identifiable points where it causes a change in phenotype as well. Thus, in contrast to the modern synthesis of Darwinism, the direction of evolutionary change is shaped as much by the pathways of possibilities generated by genetic variations as by external selective pressures producing adaptive change. The three chapters by Fontana, Stichweh and Chattoe (Chapters 5–7) will explore whether this molecular model holds promises for economics and the social sciences as well.

Economics of continuity: path dependency

Path dependency and the theorem of increasing returns have challenged some well established notions of mainstream economy. In the meantime it has been adopted rather enthusiastically by social science disciplines such as sociology and political science. The basic idea, originally formulated by Brian Arthur (Arthur 1994), may be summarized as follows: Contrary to what classical economics predicts, a growing company may not face decreasing returns with every additional product sold, but increasing returns. The reasons are manifold and include technical, social and psychological factors: a product may be combined in an optimal way with already established products; people may need the product in order to communicate with each other; or it may be too costly to learn how to handle a different design.

It depends on initial conditions, whether such externalities do indeed lead to increasing returns and, consequently, to non-equilibrium situations such as monopolies of the Microsoft type. Thus, there is a contingency element introduced into economic thinking: Small differences in initial conditions can set future economic development (of firms, of countries) onto different paths which later are only abandoned at overwhelming costs. The most celebrated case of path dependency has been the QWERTY set-up of the typewriter keyboard in the Anglo-Saxon world, which has never been abandoned although ergonomically more efficient layouts have been proposed (David 1985). Path dependency models have now been used in a wide variety of fields. They play a prominent role, to give two examples, in studies of the post-communist transition to market economies or in the process of democratization in developing countries.

Institutional inertia

The starting point of New Institutional Economics was to consider how rational man relates to institutions, thus going beyond the basically 'institution free' market models of neo-classical economics. At the beginning, the main puzzle to solve was how non-economic institutions such as property laws could emerge from the interaction of economic decision makers. In Coase's path-breaking answer to this question, they would agree on property laws if this reduces transaction costs for negotiating disputes and thus benefits all participants in a market independent of the properties they hold

(Coase 1990). In a later stage, the influence of existing institutions on the individual decision making process was analysed as well (North 1994) and institutions were conceived as products of real-world historical processes (David 1994), thus moving away from the idealized concept of a pre-historical original state from which institutions would emerge. At the same time, the meaning of institutions broadened considerably to include all types of rules, including informal ones, and consolidated routines.

Neo-institutional economics is ideally suited to map out the various trajectories of economic development since these may be preconditioned and continuously influenced by different institutional settings. Similar economic stimuli (such as market reforms) may thus lead to different economic developments, depending on the institutional set up. New institutionalism thus converged on a notion of irreversibility similar to the concept of path dependency (ibid.). It has stimulated research in political science (e.g. Thelen 1999) and sociology (Mahoney 2000 as well as in this volume), which have reformulated much older versions of 'institutionalisms' in parallel, but also in opposition to the economic strand of thinking.

The multilinear modernization of societies

The classical sociological theory of modernization envisaged a largely uniform process through which societies around the world would evolve, passing through a number of more or less predetermined stages at different speeds. The final stage was best represented by Western societies, and the US was usually taken as the apogee of modernity. The unilinearism and the teleology of these models have been criticized for decades. Against this backdrop, a series of new approaches have been developed that analyze the multiplicity of modernization paths – beginning with Julian Steward's 'multilinear evolution' (Steward 1955), to Collier and Collier's (1991) 'critical junctures', Wolfgang Zapf's 'crossroad theory' (Zapf 1996), and Shmuel Eisenstadt's 'multiple modernities' (in this volume). These different accounts vary in how they explain the mechanisms of 'branching off' into the different paths. In general, however a combination of cultural and political factors is evoked: different cultural and institutional backgrounds will produce varying reactions to modernization impulses, e.g. triggered by economic growth; and depending on the specific relations of power between social groups at critical junctures in history, a different reform path will be followed. In their emphasis of the importance of initial conditions and of institutional and cultural rules that reduce the horizon of possible social transformations, these approaches parallel the more formalized theories of path dependency and neo-institutionalism in economics.

Constellations of contingency: political history

Thinking about the significance of events for processes of change has for long been the exclusive domain of history. Traditionally, history saw the unfolding of events as a strictly deterministic process: Each event 'causes' later events to happen in a complex, idiosyncratic, yet fully deterministic way: the fog that obscured the battlefields of Austerlitz is of a different causal nature than Napoleon's brilliant strategic decisions. Both together, and a host of other events, determined the outcome of the battle. The task of the historian was to find the crucial events and to understand, through interpretation and extrapolation, how exactly they impacted on each other. Contrafactual reasoning, such as Blaise Pascal's famous dictum that 'Had Cleopatra's nose been shorter, the whole face of the world would have been different', was seen as irrelevant since Cleopatra's nose had exactly the form it purportedly did (Ferguson 1997).

In the past decade, the social sciences have re-approached history and adopted event chains as a basic explanatory model of change. There are several related strands of this 'historical turn' in the social sciences (McDonald 1996). Some have elaborated the concept of 'event' as a theoretical term encompassing the notions of sequentiality, contingency, and causal heterogeneity (e.g. Sewell 1996). In the sociology of the life course, much attention has been given to the 'turning points' of a biography, where the logic of a socially determined pathway of development is suspended and singular historical forces reshape an individual's life (Abbott 2001, ch. 8). Others in sociology, political science and history have attempted to formalize traditional historical analysis and to determine the causal importance of a particular event chain by rehabilitating contra-factual analysis (Fearon 1991; Ferguson 1997; Immergut, in this volume; Hawthorn 1991; Tetlock and Belkin 1996). Still others have reached for game theory or other tools such as event structure analysis or sequential models to understand the relevant enchainment of individual decisions and events (Abbott 2001). Finally, a group of authors from economics offered to reconcile rational choice models with the analysis of singular historical trajectories in what they termed 'analytical narratives' (Bates *et al*. 1998).

Commonalities and differences

The six paradigms have been chosen because they are all based on post-mechanistic models of change. I hasten to elaborate and justify using the notoriously chronocentric adjective 'post'. According to one definition,

> mechanisms are regular in that they … work in the same way under the same conditions. The regularity is exhibited in the typical way that the mechanism runs from beginning to end; what makes it regular is the productive continuity between stages. Complete descriptions of mechanisms exhibit productive continuity without gaps from the set up to the termination conditions, that is, each stage gives rise to the next. (Darden 2002: 356)

Many older models for analysing change described the world as composed of such machine-like mechanisms, defined by linear relationships between its parts. Cybernetic models, time series or event history approaches are examples from the social sciences and economics. If the behavior of these machine-like objects were not fully covered by the model, it was attributed to a lack of information, lack of specification of certain functions, or noise and external perturbances. Scientific progress, the credo that usually pairs well with mechanistic thinking, would bring us asymptotically close to a full understanding of the machine's functioning and a better prediction of its behavior. More precisely, mechanistic models of change may be characterized by the following four properties.

First, most models described change as the transition from one steady state to another, for example as a process driven by feedback mechanisms. The idea of systemic stability was very prominent in the functionalist tradition of the social sciences and in neo-classical economics. Societies were described in analogy to a body in a healthy state; economies appeared as perfectly balanced mathematical equilibriums modeled after equations in physics. Calls for a processual approach to understand how change actually occurred, appeared in the fifties and again in the eighties and nineties (e.g. by anthropologists Barth 1995; Firth 1992) but were largely left unanswered.

Secondly, change was seen as linear and continuous, leading from low values on a specific dimension of change to higher ones. In economics, development was modeled as a continuous process of capital accumulation and infrastructure development by early growth theorists such as Rostow (1991). Similarily, the Darwinist–geneticist synthesis of the fifties and onwards saw evolution as a continuous move, driven by selection pressures on the individual organism, towards species ever better adapted to their environment. The idea of multiple equilibria at the same level of systemic complexity was not yet well developed in economics, nor in evolutionary biology (where multi-level selection had not yet been accepted) or the social sciences (where 'Western' culture and society still counted as the model for everybody else to follow).

Third, the end point of the transition curve was known to the researcher: the models had a teleological character. In biology, it was taken for granted that evolution would necessarily lead to the higher levels of complexity of contemporary species, an idea widely copied by the social sciences in the 20th century. Fourth, change was described in many disciplines (neither in evolutionary biology, to be sure, nor in the historically minded social sciences) as a reversible process. If the behavior of a system is governed by linear relationships between its component parts, a process may be reversed to an anterior stage by lowering the value of one variable, leading to adjustments in the other variables that perfectly mirror the initial transformation, thus eventually arriving at the original state. Time, according to Einstein and also quantum theory, was an illusion (cf. Prigogine 1997). The same held true for neo-classical economics, where equilibrium can be reached in a history free space from different starting points situated in the past, present or future.

The six paradigms that will be discussed in this book go beyond such mechanistic understandings of change. They all emphasize non-linearity, partial determination, branching effects, and irreversibility, albeit to different degrees and with varying importance for the overall theoretical argument. Here is a brief summary of these four elements:

1. *Non-linearity*. In many of the paradigms presented here, a continuous change of the value of one variable may lead to discontinuous behavior of the entire system. Chaos and bifurcations are the most obvious exemplars of such non-linear behavior; they will be discussed with reference to climate change. Non-linearity is also found, albeit in a different form, in path dependency models, where changes are self-reinforcing and transition functions may expose a non-linear pattern. In climate change and path dependency models, in new modernization theory and in neo-institutional economics, small (or in some models even arbitrary) changes in initial conditions may produce different reactions to external stimuli and alternate equilibria. In evolutionary models of selection, based on population genetics and ecology, the main dependent variable is the frequency of genes whose change is often described by a nonlinear dynamical system.
2. *Partial determination*. Most paradigms include probabilistic elements and describe zones of partial determination or even of non-determination. The patterned, but aleatory moves in genotypical space in micro-biological analysis of development, the sensitivity to arbitrarily chosen initial conditions and first actors' choices in path dependency models, and the event driven trajectories in neo-historical approaches are the most obvious examples of such non-deterministic properties.
3. *Branching effects*. Non-linearity and partial determination imply that the final outcome will depend on the pathway of transition chosen. The multi-linearity that results from such branching effects is a common characteristic of most models that will be discussed in this book. It is obvious in path dependency, multiple modernities, and in event chains that may "branch out" at those events that could as well not have happened (remember Cleopatra). Branching effects can also be seen in the genotypical variations that follow a certain pathway of mutation which in turn determines the future possibilities for phenotypical change.
4. *Irreversibility*. Non-linearity and path dependency produce irreversible trajectories in many of our six paradigms of change. The economics of path dependency, climate change as a result of irreversible sub-processes such as desertification, and the sequential analysis of event chains stress irreversibility in the most obvious ways, but it can also be found in evolutionary theory (with some exceptions, as the patient reader will discover) and neo-institutional economics.

Contingency, transformation, history: three basic models of change

These commonalities are, evidently enough, of a very general nature and rest on analogies between models which work on the basis of quite different assumptions and notions of causality. It is certainly not possible to address these differences in a satisfactory way in an introduction – and a serious treatment would go beyond my own disciplinary competence and intellectual capacities. I would like to confine myself here to taking a closer look at the structure of the processes of change that these various models describe, without discussing the different properties of the latter.

In the taxonomy that follows, I will distinguish between different processual patterns that describe change – as opposed to equilibrium or reproduction. A specific model may rely on one main processual pattern or may combine several of them. The patterns thus might be understood as an elementary grammar that underlies the different languages of change.

All patterns are at least partially probabilistic and are time dependent. They can thus be described with the help of stochastic matrices. The most prominent of these matrices are those based on Markov chains, the properties of which I will now briefly introduce. The starting point is the simple idea of time as a succession of instances. Each instance can be characterized by a certain state (say A, B, and C). Thus, instance 1 may be characterized by A, instance 2 by C, and instance 3 again by A.

Transition probabilities express the likelihood that upon A follows B or C. These probabilities can be arranged in a matrix of all possible transitions, called the transition probability matrix. A matrix can contain deterministic parts (with transition possibilities of 1) and probabilistic ones (with probabilities between 0 and 1). Let me illustrate these characteristics with an often cited weather example that uses discrete time (days). Weather can only be sunny, foggy, or rainy. Contrary to his habits, the Creator has informed us about how he constructed the weather system and has provided us with the transition probabilities for these different states. We can thus draw the following matrix (see Figure 1.1). In this example, a sunny day follows on a sunny day with a probability of 0.3, a foggy day on sun with probability 0.5. There is never rain after fog.

The three patterns of change can now be exemplified with such matrices.[2] Maybe I should clarify that I use them to describe the probabilistic path through different states of *one individual system* – and not, as in many other applications, to describe the distribution of a large number of systems over the space of possible states. In order to emphasize the illustrative character of the matrices, I will not give numerical values to transition probabilities but indicate with an arrow where a transition is possible (i.e., with a probability between 0 and 1).

The first process is driven by contingency. As mentioned before, contingency is a feature of several of the models that will be discussed in this book.

		Tomorrow's weather		
		Sun	Fog	Rain
Today's weather	Sun	0.3	0.5	0.2
	Fog	0.2	0.8	0
	Rain	0.3	0.3	0.4

Figure 1.1 A basic transition probability matrix

The genotypical mutations that are at the center of biological variation follow, as the chapter by Walter Fontana will show, a structured, but principally aleatory pattern. Structure in this context means that not all transitions (mutations) have the same probabilities; the system thus 'drifts', over time, towards certain states. Contingency also appears in other, more drastic forms, such as the famous asteroid hit that changed the course of evolution – a highly improbable event that would show up only in one cell in a vastly expanded matrix with an infinite state space. The matrix may or may not show different transition probabilities, i.e. contingency may be more or less structured. Note that contingent processes may entail both reversible and irreversible transitions (from 2 to 4 but never from 4 to 2 in the left matrix of Figure 1.2).[3] A special case is a cyclical chain with only two possible states, such as the famous bifurcations of chaos theory, where the system 'jumps' back and forth, in a non-probabilistic way, between two possible states, as shown in the matrix on the right hand side (see Figure 1.2).

A second process is that of transformation. It occurs if a particular state opens up to a new subset of possible states, in other words if it leads to a qualitative change of the system (cf. Abbott 2001: 246f.). In the matrix of Figure 1.3, the system can move from the area of states 1 to 4 to the area of states 5 to 8 when it has reached state 4. Note that once the system has moved into this new area, it will not go back, the transition has a one way sign.[4] I call this process 'transformation' since the new areas of states may represent a qualitatively different state of the system or may even be described as a new system altogether.[5] An example for this type of process is the transition from one phenotype to another through what Fontana calls genetic drift in a 'neutral network'. Another example are chemical reactions, where the

Non cyclical

	1	2	3	4
1	→	→	→	→
2	→	→	→	→
3	→	→	→	→
4	→			→

Cyclical

	1	2	3	4
1			→	
2				
3	→			
4				

Figure 1.2 Contingency

combination of certain substances produces new substances with new characteristics and further possibilities of transformation (see Chattoe, in this volume). Many sociological macro-theories of change could be described by a similar matrix: The transitions are between different 'levels of modernity' that would be triggered by crucial constellations of power at the transition points in the matrix. Several such transition points would lead to Eisenstadt's multiple paths of modernization and modernities represented by different subsets of communicating states. The different paths may end in different states that would be immune to further modifications or outside perturbations.

Other variants could be described: It is conceivable to have cyclical patterns, such that state 10 would feed back to state 1, or open ended, fully irreversible processes within an infinite space of possible states, or a process which comes to an end point, such as in the matrix shown in Figure 1.3, where the process will end at what is called the 'absorbing' state 10. Imagine the infamous 'end of history' declared by Francis Fukuyama would come true; or an institutional transformation leading to an economic equilibrium.

The third pattern of change has, again, entirely different properties. Now the states are defined as events. The transition probabilities are highly unequally distributed among states and the transitions are fully non-recurrent: never does something happen twice. This matrix (Figure 1.4) adequately describes event chains as they are analysed by the neo-historical approaches discussed above. Events are seen as almost fully determined by previous events (indicated by an arrow in the matrix of Figure 1.4, with a very high transition probability), but leave room for the existence of less probable, but nevertheless possible events, which may be explored by constructing a counterfactual argument. The degree of 'historical openness' may change over the course of time and even include moments (transition from 4 to 5 in the matrix below) where probabilities are more equally dispersed over several states, thus

	1	2	3	4	5	6	7	8	9	10
1	→	→	→	→						
2	→	→	→	→						
3	→	→	→	→						
4					→					
5					→	→	→	→		
6					→	→	→	→		
7					→	→	→	→		
8									→	
9									→	→
10										→

Figure 1.3 Transformation

opening windows of contingency in the historical process. Please note that in the matrix there are events (x through $x+2$) that may have taken place if earlier events would not have happened, but will never be reached by the most probable course of history because these states are too far removed from the area of likely states. This obviously implies that we assume an infinite state space (as indicated by adding the states $x+$).[6]

Perhaps surprisingly, the patterns described by chaos theory look similar to a fully deterministic history with all transition probabilities set at 1. The somewhat paradoxical beauty of chaos theory is to demonstrate that a pattern of apparently random successive states is *de facto* fully determined by the function that defines the system – an interesting parallel to the intellectual enterprise of historians who show that what appears to be the product of pure coincidence or the free will of Cleopatra and Marc Anthony, can be understood as a chain of events necessarily succeeding each other. While the causal mechanisms leading from one state to the next are certainly conceived in different ways by chaos theory – where a single equation produces the whole sequence – and conventional history, which evokes different causes for each transition, the patterns of change they describe are strikingly similar. The abstract grammar of these matrices thus allows us to describe similarities between apparently unrelated models such as climate change and neo-historical analysis of institutional change.

	2	3	4	5	6	7	...	*x*	*x*+1	*x*+2
1	→			→						
2		→			→					
3			→							
4				→	→				→	→
5					→	→				
6						→				
7							...			
...										
x										
x+1										
x+2										

Figure 1.4 History I: event chains

Another special case of history is path dependency. The sequence starts with a set of probabilistically related states which represent initial conditions. Once the system reaches a certain state (or two such states, as in the example) within that subset, a fully deterministic path is 'triggered' off, which is fully irreversible. The path may or may not end in stable states, such as in the matrix below where 7 and 10 are absorbing states; or it may again 'open up' to a subset of various probable states, i.e. the path is unlocked at a certain state (as discussed in Castaldi and Dosi's chapter).

Contingency, transformation and history are the three basic post-mechanistic patterns of change that I have identified here. Others may be added. More complex matrices would allow for continuous time, for changes unequally dispersed over time periods (such as in Poisson processes), and for 'deeper chains' where not only the current, but also past states influence the future, a very important modification for the social sciences that deal with systems that have memories. I offered these matrices for strictly heuristic and illustrative purposes: To suggest in which direction one could search for

	1	2	3	4	5	6	7	8	9	10
1	→	→	→							
2	→	→	→					→		
3	→	→	→	→						
4					→					
5						→				
6							→			
7							→			
8									→	
9										→
10										→

Figure 1.5 History II: path dependency

an elementary grammar of change which underlies the various post-mechanistic paradigms discussed in this volume and beyond.

Concept migration between disciplinary fields

I should now like to shift perspective, and look at how these paradigms have been applied across disciplines. Each originated in specific fields, from physics to chemistry, biology, economics to history. Their success has often drawn attention from scholars working in other fields who then used them to answer questions specific to their own disciplines. The problems and prospects of such concept migration will be the topic of this section.

It will be a general discussion drawing on the philosophy and history of science and making references to the chapters whenever appropriate. There is a small, not yet well connected literature on how to understand under which conditions and with what consequences model migration occurs. So far, this literature has generated various typologies, which I should like to synthesize in the following. Five different modes of what has variously been termed ‘borrowing’, ‘exchange’, ‘import’ and ‘export’ (or assuming the perspective of the concepts: ‘transfer’, ‘migration’, or simply ‘move’) will be distinguished.

The typology differentiates between the various types of intellectual goods that trespass the boundaries between disciplines.

Tool transfer, model migration, methodological analogies, and metaphor move

The first type is the transfer of a research tool, such as a statistical technique, or a mathematical model, or a computer program. Renate Mayntz (Mayntz 1990: 58) lists Thom's mathematical catastrophe theory or Haken's synergetic as examples of mathematical models that have been adopted by the social sciences. Other instances would be the spread of Bayesian logics to different fields, including sociology (Ragin 1998), the use of optimal matching methods originally developed for DNA sequences by historical sociologists (Abbott 2001), or the cladistic method for determining the historical relation between species applied to language history (see Cracraft, this volume).

A second, more demanding type is to integrate not only a mathematical/statistical technique, but to make sure that the theoretical propositions as well as the empirical terms, i.e. an entire model, find their corresponding propositions and terms in the importing field (see the definition by Morgan and Morrison 1999). There are two variants of such model depending on whether or not the model is respecified in the new field. Accordig to Mayntz (1990) re-specification begins with theoretical generalization, during which a model is stripped of any empirical specifications, and is completed successfully when it has been linked to the new empirical field through new operationizable terms. She cites the sociologist's Niklas Luhman's adoption of general systems theory as an example of this type of model transfer.

In a more literal translation of a model without respecification, the importing researcher looks for one-to-one analogues for each of the terms of the model and makes sure that the causal connections between the terms remain intact. This is what an ample literature in the philosophy of science from Duhem to Campbell to Harré and Hesse describes as an analogy (for an overview see Bailer-Jones 2002: 110–14). Both the less and the more strict forms of model migration may lead to a complete 'assimilation' of the imported model, to a degree where its disciplinary origin may no longer even be remembered (see Klein 1996: 63).

The third mode of borrowing is much less demanding: fewer conditions have to be met for a successful transfer. It concerns methodological strategies rather than models that specify causal connections between empirical terms. A prominent example is the role that non-linear physics played in reshaping the notion of causality in the social sciences, which have been the last to depart from the epistemological ideal of Newtonian physics and full determination. The search for corresponding 'laws' governing the social world has now been abandoned, since it is assumed that if the natural world is full of probabilistic processes or non-linear phenomena, there is a high probability that similar processes govern the social world as well (Mayntz 1990; Urry 2004). According to Kellert (2000: S464), even such loose transfer of methodological principles has to rely on a quite precise analogical operation: Only when we can be sure that the principle characteristics of two fields are sufficiently similar can we assume that the methodologies successfully applied in one field will yield the expected return in the other field as well. A good example is Kiel's plead (in this volume) for searching for non-linear phenomena in the social sciences similar to those of chaos theory in physics and biology, given that the social world is structured in a similar way as the natural world. Another example would be the methodology of contra-factual thinking that Ellen Immergut is introducing in this volume and that may be of importance to other disciplines where single events shape the course of change in a non-experimental setting.

The most controversial form of cross-disciplinary borrowing concerns metaphors. Metaphors are often used to illustrate complex causal models. The 'butterfly effect' or 'emergence' in complex systems are frequently cited contemporary examples. The use of the Judeo-Christian and other powerful metaphors of time in geology (Gould 1988) or sociology (Nisbet 1969) represent well studied cases. Darwin borrowed the metaphorical image of the 'survival of the fittest' from the social scientist Herbert Spencer.

The borrowing of metaphors is discussed, in this volume, by Ghadakar, Kiel, Chattoe, Stichweh and others. Authors are divided, as is the literature, about the worth of metaphor migration is fruitful. Ghadakar points to the dangers of misinterpretation when the normative implications of a metaphor (such as genetic 'fitness') is transposed to another field (such as human society). Kiel is more optimistic and assumes that metaphors from other disciplines may help to overcome routinized patterns of thinking and thus stimulate innovation. This is an argument also presented by Kellert (2000), who describes the effects of metaphor transfer as one of 'deformalization' and thus creative confusion.

Cognitive research on metaphor use helps to understand why migration of metaphors may stimulate innovation. Metaphors provide a new perspective on a topic because they bring to the foreground less salient properties of an empirical object by linking them to the primary properties of the metaphorical image (see the 'salience imbalance' theory of Ortony 1993). In other words, a new metaphor allows us to see an empirical field with new eyes and may thus stimulate new research strategies (see the 'interaction view' on metaphors developed by Black 1993: 35–8). Brüning and Lohmann (1999) have shown, building on Peirce and a case study from oceanography, how new metaphors may develop into models of causal relationships which then are specified, loose their metaphorical quality and may be subjected to empirical tests. Metaphor import can represent, in other words, a 'soft' initial stage in the process of scientific discovery.

Risks and obstacles

Tool transfer, model migration, the borrowing of methodological strategies, and metaphor migration are the four modes of cross-disciplinary exchange that I distinguished in the previous section. All share some problems and risks that are rarely mentioned in this scarce literature dominated by enthusiasts of interdisciplinary co-operation and that are advocates of disciplinary unbounding. I should like to discuss the most obvious ones here.

First, most ideas are transferred long after they have become established in the original field. It takes further time for the new methodology, model or metaphor to be mainstreamed into normal science of the importing field. It may well be that a model, methodology or metaphor is most popular in the new field when it has already been abandoned as a consequence of a paradigm shift in the original field. Many have observed, including Fontana and Chattoe in this volume, that much of mainstream social science still tries to imitate a Newtonian model of physics that has long been revised in favor of a probabilistic approach by physics itself. Another example, within the social sciences, is the current popularity of anthropology's traditional concept of culture, which anthropology has abandoned almost a generation ago (Wimmer 1996).

A second, equally obvious danger is that of misunderstanding. One of the most prominent and obvious examples is that of path dependency, which has often been reduced to a vague notion that 'history matters'. Economics, as Castaldi and Dosi make clear in their contribution to this book, has a much more precise idea of how exactly Clio steers the flow of events. Perhaps even more misused is the notion of chaos, which borrowers have understood as representing indeterminacy and pure stochasticity (cf. Kellert 2000). Some of these misunderstandings are simply based on poor scholarship and thus may not provide enough ground for a general critique of concept migration. Ghadakar's warning against the undesirable implications of metaphor migration should certainly be taken seriously, especially by the social scientists in whose hands concepts such as the 'selfish gene' may produce dubious results (cf. Segerstrale 2001). However, his caveat is clearly not directed against concept transfer as such.

A more serious danger is that of misapplication. Several examples have been identified. According to Lorenz, in this volume, chaos models have been applied to economics without a proper re-specification of the underlying causal propositions, about economic behavior many of the implicit assumptions. As a result, on which the models rest do not make sense from an empirical point of view. In addition, chaos often appears in value domains which are beyond those actually observed in empirical reality – the model thus describes a theoretically possible behavior with little chances of actual occurrence.

In addition to such mis-specification, a model transfer may be criticized as not capturing the relevant aspects of change in the new domain. In his contribution to this volume, John Harriss criticizes the use of neo-institutional approaches to explain social and political phenomena. He argues that social and political change are effects of the transformation of power structures and the cultural patterns linked to them. Both are, however, treated as exogenous variables in the institutionalist approaches. According to his view, adopting a neo-institutionalist frame of analysis therefore adds little value to the sociological enterprise.

Finally, model migration can be risky because differences in the properties of the importing and exporting fields may make a successful re-specification improbable. The analogical operation discussed in the previous section may fail. The most prominent example that comes to my mind is the use of evolutionary analogies in the social sciences. It has been argued time and again (cf. Chattoe, this volume) that the 'environment' which selects variations is not independent, in social systems, from these variations themselves, basically because humans may intentionally manipulate environmental conditions and co-operate with each other to do so.

Mis-specification, irrelevance, and misfit thus represent the major risks that models, metaphors, and methodologies encounter in new disciplinary territories. Despite these risks, traffic on the cross-disciplinary roads is dense. It seems that the barriers to such traffic cited in the literature – e.g. different intellectual cultures and epistemologies (Bauer 1990) – are no longer, if they have ever been, substantial enough to prevent such flows.

The reader of the following chapters will discover, however, that not all roads are traveled in both directions: Chaos theory emanated from mathematics and physics and moved to the natural sciences, economics and the social sciences. Evolutionary biology inspired economics and the social disciplines. Path dependency moved from economics to sociology and political science. Game theory (not discussed in this volume) was originally developed by mathematicians and economists. In the meantime, it is widely applied in evolutionary biology and political science as well. We are not aware, however, of any major social science concept having been adopted over the past decades by economics (with the possible exception of the 'trust') or the natural sciences – the days when Spencer inspired Darwin seem to be gone by now (again with one possible exception: small world theory [Watts, 2004]).

In other words, the dialogue that this book documents exhibits a rather asymmetrical character. The reader will notice that the natural scientists and economists commenting on the papers by Shmuel Eisenstadt and Ellen Immergut had to overcome considerable difficulties in finding an adequate point of view from which to discuss possible links between comparative historical sociology and institutionalist political science. The same holds true for the natural scientists discussing the two economics papers. Reinforcing this impression of asymmetry, the editors have to admit that it has been challenging to find natural scientists who were prepared to comment papers far removed from their disciplinary domain and area of expertise – we are all the more grateful for the excellent contributions, written by outstanding scholars, that we eventually received.

Several explanations for this asymmetry have been put forward, of which I will mention only three here. First, Pantin (1968) has observed some time ago that the natural sciences are more 'restricted' disciplines with very strong linkages between research areas within their disciplinary domains and weak and few ties with other disciplines. The social sciences, by contrast, are 'unrestricted' disciplines with more fuzzy cognitive borders and greater openness to exchange with other disciplines. Economics would be situated somewhere in the middle. Secondly and related to this, there seems to be a flow gradient of borrowing from the more mathematical to the less mathematical disciplines, which may be explained by simple intellectual economy: It is easier to re-specify a model that contains an abstract mathematical core than to first generalize the usually context specific, discursive models of the social sciences into a mathematical language and then re-specify it. Finally, we should mention the asymmetry of power and prestige between disciplinary fields (cf. for France Bourdieu 1988). Concepts emanating from the most highly ranked disciplines, such as theoretical physics, enjoy a nimbus of truth and relevance that those for example from administrative studies will never have. Conformingly, the likelihood that a specialist in administrative science will learn, through the media or the feuilleton, of the latest revisions of the theory of black wholes is much higher than that a theoretical physicist will ever come across the advances in the theory of institutional learning – although it is probably safe to say that the latter may be of much greater importance for the daily life of both individuals than the former.

This last point may help to understand why even the more formal models of the social sciences that would offer themselves as an import good remain unnoticed by economics and natural sciences. An apt example are the advances that have been made, over the past decade, in formalizing the traditional historical method and to develop more rigorous models of the unfolding of events (see Mahoney, this volume). These models (e.g. Abbott 1995; Heise 1989; Abell 1993) are suited to explain event chains, some of them in a comparative way, and thus go beyond the descriptive story of 'one damn thing after the other', as a popular saying describes traditional history. These developments have not been, as Mahoney points out, noticed by economists and natural scientists, although we find plenty of evidence for historical processes in their fields – for chains of events which influence the systems in question in a quite fundamental way and yet have to be treated as noise or contingency by most existing models.

Three examples may suffice to illustrate this point: In the ecological analysis of biota – the combination of species in one particular natural environment – geological events such as volcano eruptions greatly influence the possible migration of species across ecological space and thus the composition of a particular biota. In evolutionary biology, Eldredge and Gould's famous essay on the role of events, such as the appearance of a dramatically fitter mutation or a drastic change in the environment, has sparked a lively debate between gradualists and adherents of the 'punctuated equilibrium' theory (Eldredge and Gould 1972). This debate has not taken notice, to my knowledge, of the arsenal of models and methodologies that the social sciences offer for analyzing event chains. In the economics of path dependency, as Castaldi and Dosi note in their chapter, researchers struggle to deal with the fact that not only initial conditions, as in the original path dependency model, but also subsequent external events shape the development trajectory and can even lead to the abandonment of a given path.

Innovation in the trading zone

Despite the various risks and obstacles to import models, metaphors and methodologies from other disciplinary fields, it remains one of the major sources of innovation in all branches of the sciences. While there is no quantitative study, to my knowledge, that would establish this point, there is a small, yet growing qualitative literature in its support. The romantic legacy of viewing the 'context of discovery', in contrast to the 'context of justification', as the domain of a genius' flashes of insight or of pure luck has long obscured the patterns governing innovative processes in the sciences (Meheus and Nickles 1999). Concept transfer from one domain to another represents one important element of this pattern, together with abduction, thought experiments and heuristic rules governing exploratory research in uncharted terrain. Tool, model, and metaphor transfer each have contributed to major innovations.

The best evidence for the importance of tool transfer comes from physics. Rebaglia (1999) shows that major breakthroughs were achieved by importing mathematical tools and applying them to the physical world. The literature is more ample when it comes to model migration (Bailer-Jones 2002: 110–14; Klein 1996: 61–6). A large number of examples of model import in the hard sciences have been discussed: Bohr's atom model developed through analogies with the solar system; electromagnetic waves were modeled after d'Alembert's vibrating strings equation; Coulomb's law was applied to gravitation, electrostratics, and magnetnism; nuclear fission was conceived in analogy to the division of a liquid drop. Examples from economics and the social sciences abound as well: the structuralism of Lévi-Strauss borrowed models from Jacobson's linguistics; anthropological structuralism then moved to psychology (Lacan), sociology and philosophy (Althusser) and political economy (Rey). Game theory models traveled, as mentioned before, from mathematics to economics and from there to political science, sociology, and evolutionary biology. The list of examples seems to be endless. We are left wondering, lacking a more systematic study of the subject, if we could find any process of innovation without some sort of analogical reasoning.

The innovative capacities of metaphor borrowing are less well documented in the literature, partly because the definitional boundaries between models and metaphors has become more and more blurred recently. Many philosophers of science now to look more closely at the metaphorical qualities and functions of all models, even highly formalized and mathematical ones (cf. Bailer-Jones 2002). At least we dispose of case studies on the innovative effects of the transfer of metaphors (in the more restricted sense of the term) (Brüning and Lohmann 1999). It seems that metaphor migration plays a far more limited role in the natural sciences – again due to their 'restricted' character – where model import from neighboring fields or disciplines is much more common than borrowing metaphors from completely different areas of research (see Dunbar 1995 on 'local, regional and long-distance analogies').

Concept borrowing thus represents a core element of innovation and discovery within a discipline. At the same time, it changes the relationship between areas of research by providing new intellectual contact points and avenues for cross-disciplinary co-operation. In order to adequately grasp these effects, we may refer back to the metaphor of a 'trading zone', coined by Galison (1997) to describe the intersections of the different professional cultures of experimenters, instrument makers and theorists in experimental microphysics. In a trading zone, people from mutually incomprehensible cultures come together to trade objects of interest. They develop a highly-restricted proto-language or pidgin for these negotiations. This pidgin allows them to reach agreement about objects of trade even though outside of the zone, within their own cultures, their understandings and uses of these objects differ radically.

The objects of such minimal understanding may be techniques, devices, and most importantly in the context of this introduction, shared concepts, models and metaphors. Löwy (1992) has developed the notion of 'loose concepts' which 'help to link professional domains and to create alliances between professional groups' (Löwy 1992: 373), such as immunologists and epidemiologists. Similarly, Leigh Star and Griesemer (1989) have identified 'boundary concepts', 'adaptable to different viewpoints and robust enough to maintain identity across them' (ibid.: 387) as crucial elements that bind together different disciplines and professional groups.

According to Galison and Löwy, the pidgin may further differentiate and evolve into a shared medium of communication, a 'creole language'. Examples of such highly integrated zones are quantum field theory where particle cosmology, mathematics, and condensed matter physics interact (Galison, forthcoming) or molecular genetics, where micro-extraction and micro-dissection, advanced combinatories, statistics, thermionic optics and the chemistry of enzymes coalesce around the model of the double helix (Canguilhem 1984: 148).

These are large research enterprises of experimental physics or the research departments of big museums, where representatives of different disciplines and professions are co-operating on an institutionalized basis. Examples of fully integrated creole languages to understand change are still rare. Perhaps closest to such fully co-operative and institutionalized research communities are the climate change research discussed in the opening chapters of this book. Another example, not represented in this volume, are those programs where economists, biologists, neuroscientists, psychologists and anthropologists co-operate, often using advanced game-theoretic models, to understand the emergence and further development of co-operation in animal and human societies. So far, these endeavors are comparatively loosely organized in research networks (such as the McArthur Preferences Network) or conferences (see Hammerstein 2003). They focus on very specific behavioral phenomena such as reciprocity in small groups and other small scale social patterns.

This book pursues the more modest aim of both documenting and furthering the cross-disciplinary dialogue around shared models, metaphors, and methodologies for understanding change. It contains examples of all the different types of exchange discussed in this introduction: tool transfer, model migration, the borrowing of methodological strategies, and metaphor move. It illustrates and discusses the various risks involved with conceptual borrowing, namely misunderstanding, misapplication and misfit. Most importantly, it sheds some light on the innovative potential of trading metaphors, models and methodologies. Finally, it offers some goods for future exchange: To apply non-linear systems dynamics to large-scale modernization processes (Somdatta Sinha); to use contra-factuals (Ellen Immergut) or event-chain analysis (Mahoney) for the study of historical events in the natural and economic sciences; to research discontinuous social processes with the model of neutral networks (Walter Fontana; Rudolf Stichweh); to use models of chemical reactions to understand institutional transformations of human societies (Edmund Chattoe); to export the cladistic method for studying phylogenetic change to the social sciences (Joel Cracraft). The remainder of this introduction is dedicated to a preview of each individual chapter.

The chapters

Paul Higgins focuses on the relevance of chaos theory for understanding macro-level climate change. Analysis and prediction of climate phenomena depend on particular spatial or temporal scales. In contrast to short term fluctuations in weather, longer-term climate characteristics such as the seasonal cycle are primarily determined by regular periodic forcing (e.g., the earth's orbit) and are generally predictable. However, interactions between sub-units of the climate system (e.g., ocean, atmosphere, cryosphere, and biosphere) do sometimes lead to complex behavior such as abrupt change or multiple equilibria not evident when each sub-unit is viewed in isolation. These characteristics of the climate system (unpredictability or chaotic dynamics occurring at some scales, but not precluding deterministic projections at other scales; complex behavior resulting from interactions between sub-units of the system) are likely critical for studying other processes of change as well. Thus, the analysis of anthropogenic climate change could benefit from and contribute insights to other, empirically unrelated studies of change in complex macro-level systems.

L. Douglas Kiel takes up the discussion where Paul Higgins leaves it and evaluates the prospects of transferring chaos theory to the social sciences. While social scientists have for many decades recognized the nonlinear nature of social phenomena, they have lacked the appropriate theoretical and methodological tools. The chapter looks at three modes of 'paradigm export': (1) The use of advanced mathematics for discovering chaos in time series, which, however, does not help much in explaining why such phenomena occur. (2) Chaos has also been used in a more metaphorical sense to understand change in complex social systems – a potentially powerful way to overcome linear thinking so prominent in the social sciences. (3) Agent-based modeling as a way of approaching emergence and complex change in the social sciences, represents an alternative way.

Hans-Walter Lorenz reviews what experiences economics has made with chaos theory over the past two decades. He cautions that while it is hardly difficult to discover chaotic behavior in economic systems described by standard differential equations, this behavior is often not relevant from an empirical point of view: sometimes chaos emerges on the basis of empirically unrealistic ad hoc assumptions or of parameter values beyond any empirical scope. Even when there are no doubts about the empirical relevance of chaos, technical problems such as the low number of observations in time series and problems of interpretation (such as misreading 'Monday' effects in stock markets as chaos) remain. In the second part of his essay, Lorenz moves beyond model export to more generally discuss the prospects of interdisciplinary research on shared empirical problems. The multi-system approach to climate change does indeed offer an opportunity to establish a 'tracking zone' between environmental economics and to natural and social science research, despite different degrees of formalization and different normative definitions of the aim of trade.

Evolutionary theory remains the core paradigm of change for the biological sciences. It has seen a dramatic development and expansion since the formulation of the modern synthesis combining Darwinian principles with the insights from molecular genetics. Walter Fontana's paper focuses on genetic variation as one particular aspect of the overall evolutionary dynamics. He offers a model of the genotype–phenotype relation that illuminates how genetic change produces phenotypic change. The model uses a simple molecular instance of such a relation based on the shapes of different RNA sequences that can fold into different forms, the equivalent to a phenotype. The genotypical changes are described as movements in a multi-dimensional space of possible mutations that at certain points result in a shift of phenotype. Some genotypical mutations thus are 'neutral' with regard to phenotype, while others are leading to change in the appearance of the species. The result is a discontinuous, punctuated process of evolutionary change. In a final section, Fontana suggests to export this model into economics and the social sciences by relating genotypical change to modifications in behavioral rules and phenotypical change to institutional and organizational change.

Is this concept of 'neutrality' fruitful for thinking about change in social systems? Rudolf Stichweh's paper discusses two possible applications of Fontana's model in the social sciences. Structural changes, e.g. in the class system of a society, may be neutral with regard to the basic principles of social organization, such as functional differentiation. Secondly, semantics and culture can drift through spaces of meaning without any changes in social structures immediately resulting from this. Even if these are not exact analogues, further exploring the similarities and differences is a promising avenue for future research, the chapter concludes.

Edmund Chattoe's chapter begins with a general discussion of the role of analogy in the history of thought – in the way the term was introduced by Hesse, thus broadly synonymous with what I have termed model import without re-specification and described as, the most demanding form of concept transfer. He then considers the potential benefits of evolutionary analogies for social sciences, and of economics in particular: their non-teleological character, their ability to understand endogenous variation (instead of introducing outside 'noise' from the space they provide for the emergence of new forms. The main body of the chapter presents two case studies inspired by Fontana's work. The first applies the concept of neutral networks to the analysis of social change. He concludes that the model misfits the specifities of the social world because, the classic problem to find an analogon to a selecting environment cannot be overcome. The second case study uses 'algorithmic chemistry' to explore the problems of industrial diversification and of the emergence of classes. He again notes important problems but concludes that this might be a more promising example of model export.

Carolina Castaldi and Giovanni Dosi introduce the concept of path dependency as it originally developed in economics. The chapter opens by appraising the potential for path dependencies and their sources at different levels of observation and within different domains. It then gives an overview of the modeling tools available economics. They note that during the last decade, the metaphorical use of the path dependency argument has become very popular. However, challenging questions remain regarding when and why path dependency effects do indeed occur. Usually, only one of the many possible paths that some 'initial conditions' would have allowed is actually realized – opening up the problematic space of contra-factual reasoning. Moreover, is path dependency shaped only by initial conditions or also by the unfolding of events that happen further down the road? How do socio-economic structures inherited from the past shape and constrain the set of possible evolutionary paths? And finally, what are the factors, if any, which might de-lock socio-economic structures from the grip of their past?

James Mahoney first discusses the principle of increasing returns as the core of path-dependency models in economics. He goes on in exploring the particular combination of determinacy (once a path is chosen) and indeterminacy (in the initial choice of a path) that characterizes this model and shows how similar reasoning has prevailed for a long time in social sciences, where path dependency may be much more frequent than in economics. The mechanisms that produce increasing returns, however, are different in non-market contexts and include the self-reinforcing character of political power and the functional interlocking of institutions. The social sciences have developed modes for analysing path dependency that include the study of de-locking and reversible trajectories. He specifically discusses models of 'reactive sequences' and 'event chains' and concludes by hoping that these new developments in the social sciences may inspire economists to explore similar avenues.

Eörs Szathmáry's chapter discusses how the evolutionary mechanism of natural selection can lead to various forms and varying degrees of path dependency. He describes different aspects, situated on different scales from the palaentological to the microbiological and includes different points of view. Special attention is given to how different hereditary mechanisms (genetic, chemical, epigenic, cultural) determine the degree of replication/variation as well as reversibility/irreversibility. He then shows that evolution is not always fully irreversible: some genes and traits can be resurrected if relatively little time has elapsed since their disappearance. However, the so-called major transitions in evolution, such as from cloning to sexual reproduction or from single-celled organisms to animals, illustrate the awesome power of path dependency in biological evolution. He explains how the apparent contradiction between such historical contingency and evolutionary convergence, e.g. towards analogous organs such as the eyes of squids and humans, can be resolved by looking at engineering constraints and the details of the convergent traits.

Jeffrey B. Nugent introduces new institutional economics as an ensemble of several different, though interrelated approaches. All are relatively recent developments that are only now being added to the standard tool box of 'neoclassical' economics. The most important of these are: transaction and information costs analysis, property rights theory, and the theory of collective action. Thus far, all three models have focused largely on static issues, explaining 'why institutions are the way they are'. The main purpose of his chapter, however, is to evaluate their potential for understanding change and development. He identifies the difficulties in applying new institutional economics to this task, but also offers some examples of at least partial success such as a neo-institutionalist account of why property rights developed differently in North and South America. He concludes by pointing to what has been learned about the relationship between institutional and other dimensions of change.

John Harriss, however, questions even these modest claims to explanatory power. Referring to the example of differing developments in various Indian provinces, Harriss argues that new institutional economics may serve to highlight the importance of power and of politics in understanding these differences. However, it does not in itself explain power and politics but treats them as exogenous variables. The new institutional economics thus represents a useful heuristic device that directs our attention to particular facts that then need to be explained by taking recourse to the analytical tools of the 'old' institutional analysis of a political economy type. A similar point is made with regard to cultural habits of thinking and acting which are closely related to power structures and yet find no place within the neo-institutionalist framework.

Raghavendra Gadagkar follows up with more general reflections on the prospects and dangers of cross-disciplinary borrowing. The first part of the chapter explores some parallels in the institutional set-up of human society and social insects. It specifically deals with the honey-bee dance used to indicate location of food sources, with fungus agriculture among ants, and with the division of labor between queens and workers among social insects. He shows that similar questions as those raised by new institutional economics have been asked by natural scientists studying these phenomena – which leads him to plead for more interaction between natural scientists, economists and social scientists.

In the second part of his chapter, he qualifies this plead by distinguishing between exporting methodologies, concepts, and metaphors. Exporting methodologies, especially those based on direct observation and measurement such as behavioural experiments, is usually fertile, especially for the importing social sciences. Exporting concepts, such as those developed by new institutional economics, may prove to be productive, including for the importing natural sciences. However, a transfer of metaphors (such as 'survival of the fittest') from one field to the other entails great risks because metaphors are usually loaded with value judgments that are misleading when transferred across disciplinary boundaries.

Shmuel Eisenstadt explores the importance of the idea of multilinearity and path dependency for the social sciences. His point of departure are the teleological assumptions of most classic theories of change in this field. Modernity, defined by a high degree of cultural openness combined with the politics of protest and contestation, has indeed spread to most of the world. However, it did not give rise to a single civilization, or to one institutional pattern, but rather to several differing cultural and institutional forms. He identifies the main reasons for this multilinearity: differing initial cultural conditions; specific power constellations between established and protesting elites; initial institutional frameworks that influence future institutional arrangements; and differing ways of incorporation into the global system. Finally, Shmuel Eisenstadt also questions the optimistic tone of much modernist writing about change, pointing to certain cultural and political variants of modernity that may lead to unseen mass violence and suffering.

Oded Stark opens his chapter by picking up on Eisenstadt's pessimistic concluding note. According to Stark, a major difference between social sciences and economics is that the former lack a clear basis for a comparative evaluation of different societies, while the latter can rely on measurements of economic efficiency or overall output levels to judge which of the various 'modernities' is preferable. Contrary to what many sociologists and economists like to think, however, those variants of modernity that favor trust among unrelated individuals need not be more efficient as Stark argues with the help of an example from game theory. The chapter also offers an economic explanation of why modern societies are, according to Eisenstadt, characterised by the politics of protest. They integrate greater numbers of individuals into a communicative space and thus enlarge the reference group for comparing one's own economic standing. As a result, dissatisfaction – and hence the propensity to protest – may increase despite increasing incomes.

Does the development of 'multiple modernities' bear any resemblance with evolutionary processes in the natural sciences? Somdatta Sinha shows that though the language and argumentative styles in these two research fields are quite different, there is a convergence of models and metaphors converge. According to nonlinear dynamical systems theory in biology and physics, systems with multiple variables and nonlinear interactions behave similarly to Eisenstadt's modern societies within the world system. She specifically discusses three ways in which multiplicity emerges first, as bifurcations in a system's behavior when an internal variable reaches a certain value; secondly, as diverging reactions of only minimally different systems to identical external stimuli; and finally, as different responses to different stimuli, depending on which variable is most affected. She concludes that most, yet not all of these properties can also be found in Eisenstadt's account of the history of the modern world. Emphasizing the second mechanism for the production of multiplicity, i.e. that small differences in internal structure may make a big difference in reactions to outside stimuli, she warns against oversimplifications such as the contrasting of a 'Muslim' versus a 'European modernity'.

While the preceding part dealt with the long term macro trends of social change, Ellen Immergut's chapter focuses on short term developments – the daily weather, as it were, in contrast to climate change. What is the balance between the continuity of self-reproducing political institutions and path breaking events? Immergut pleads for a pragmatic, case by case approach and for the use of historical methods to address this question. Historical methods are especially suited to elucidate three crucial problems in the study of the political: the question of how actors change their preferences and definition of their interests; the interplay of changing institutional rules and chains of micro-political events that produce 'contextual causality'; and contingency as it interacts with institutional routines. The partial reforms of the Swedish constitution in 1968 and 1969 represents an ideal case study to explore the potential of this approach. Why did members of the Social Democratic Party agree to eliminate constitutional provisions that guaranteed their hegemonic position at a time when they held the parliamentary majorities necessary to veto any and all legislation, including constitutional reform? Ellen Immergut relies on a historical counterfactual and the study of actor's perceptions and motives in order to answer this question. The case study illustrates the hazardous, unpredictable nature of institutional change and therefore the importance of historical methods for its proper understanding.

Roger Congleton takes up the problem of contingency and chance in human history but arrives at different conclusions. While historical research aims at understanding the particular, e.g. how exactly Swedish constitutional change came about, the social sciences explain general trends and patterns, such as the emergence and spread of democracy in Western Europe and beyond. They are therefore unable to make sense of individual events, which are not entirely determined by the general mechanisms. Such contingency is introduced into the historical process because actors do not have complete information about the future and therefore are prone to take sub-optimal decisions with regard to their rational interests. The Swedish constitutional change is a case in point. Such examples do not, however, contradict the rational choice model of decision making which remains, the author implies, the most powerful model of explaining change in the social sciences.

Joel Cracraft opposes the notion of contingency on similar grounds as does Congleton – and in quite striking contrast to the other evolutionary biologist writing in this volume, Eörs Szathmáry. Perhaps the most prominent argument in favor of contingency and of contrafactual thinking in biology is Gould's point that evolution would have taken a different course if a major asteroid would have missed the earth some 65 million years ago. However, Cracraft argues, contingency only matters for micro-level phenomena and not for the large scale systematic changes in the structure of species or the institutional makeup of society. These systematic changes can actually be explained with a covering law model. In the social sciences, these laws would certainly be of a probabilistic nature and would have to be based on a better identification of the units that change than it has been the case so far. Even in explaining micro-changes, however, contingency and contra-factuals are of limited significance. They may help to explain the effect that a defacto event actually did have. But it is futile to construct alternative versions of future developments assuming that one particular event had not occurred, since we never know if future events would have 'undone' the effects of changing this one link in the historical chain; if in other words, the hit of a second asteroid would have reversed the effects of the first – an argument which seems to lead the author back the classical historiographic approach of Leopold von Ranke, who exhorted his colleagues to exclusively focus on history 'wie es eigentlich gewesen (how it really was)'.

Acknowledgments

This book is the product an unusually long journey, the perhaps inevitable consequence of its scope and ambition. Two thirds of the chapters are based on the papers given at a conference that the two editors had organized at the Center for Development Research of the University of Bonn in May 2002. The list of persons who have helped and encouraged us to realize the conference is long.

Almost two years before it took place, Yehuda Elkana had given me the advice to first read seriously across the various research fields before starting to put together a conference program. This conversation in a coffee shop in Budapest proved to be a crucial initial event for the further – path dependent? – development of the project. I owe him a long and rich experience of intellectual discovery and excitement. On the other hand, he is also to blame for having me realize the limitations of my intellectual horizon and, more painfully, of my cognitive capacities. In this case, the usual disclaimers do not apply.

Most of the reading was done during my stay at the Wissenschaftskolleg Berlin, which provided an ideal environment for this exercise in disciplinary unbounding. Many cofellows amusedly observed my first steps into their fields and put me back on my feet when I had fallen. Leticia Avilez was particularly patient and sympathetic.

Reinhart Kössler soon joined me in the preparatory reading and the organization of the conference. He proved to be an ideal companion and partner to put the project on track. We have received advice and many valuable suggestions regarding conference and book participants from too many people to name them all. Joachim von Braun, Luis Mata, Paul Vlek, and Peter Wehrheim from the Center of Development Research helped to orient ourselves in the fields of ecology and economics. We are especially grateful to Luis for identifying approaches and persons in the domain of climate change. Raghavendra Gadagkar from the Wissenschaftskolleg and Hans-Jörg Rheinberger of the Max-Planck-Institute for the History of Sciences provided critical inputs. Markus Beiner from the Volkswagen-Foundation ensured financial support for the conference. The Center for Development Research has upheld earlier commitment to provide financial assistance to the book project. Valuable research assistance came from Karina Waedt. We thank them all.

Notes

1. I thank Rick Grannis for helping to avoid some initial confusion regarding the Markov chains used in the second section of this chapter. Bettina Heintz's suggestions put me on the right path searching for literature on model transfer. Special thanks go to Somdatta Sinha and Giovanni Dosi who both offered detailed

comments and suggested important improvements to make the matrices 'work'. Giovanni patiently explained the properties of chaos theory until I finally got it. Walter Fontana and Paul Higgins have edited parts of this chapter and saved me from many imprecisions and misunderstandings. I am afraid the remaining ones are my sole responsibility.

2. Such matrices can have a variety of characteristics, some of which are relevant for my purpose. In the standard matrices such as the weather example above, all states can be reached from other states in a finite number of steps. This is an *irreducible chain*. If the path always leads back to a state through a determined number of moves, we speak of a *cyclical* chain or a periodic chain. Chains without such cyclical moves are called *aperiodic*. If there are states that do not lead to any other states, i.e. with transition probabilities to all other states of 0, we call this an *absorbing state* (imagine that the first sunny day would be followed by sunny days forever). If there is a group of states that only lead to the states within that group but nowhere outside, mathematicians speak of an *ergodic set* (or chain, if the states comprise all possible states). The number of possible states can be finite (*a finite state space*) or infinite. A state space may contain a subset of spaces that communicate with each other with much higher probability than with all other states. The chain is then '*nearly completely decomposable*'. For some chains, we know where to start, i.e. the initial probability for a certain state is 1. In others there are several possible initial states.
3. This chain would be described as irreducible; it has a finite state space with no absorbing states or decomposable subsets; it is fully ergodic; and the initial state probabilities are not known: the process can start anywhere.
4. This chain is a periodic and not irreducible. I assume that this could be described, in mathematical terms, as a nearly completely decomposable Markov chain.
5. Note that transition probability matrices are not the adequate tool to describe the nature of these qualitative changes. They only characterize the probabilities, the pathways and the time necessary to achieve such changes. Nonlinear system dynamics may be a more adequate tool to model the actual transformations of the system's behavior by referring to changing internal and external parameters.
6. Note also that history is fully aperiodic, non-recurrent, has no absorbing states and is not irreducible. In other words, something new always has to happen.

Bibliography

Abbott, Andrew. 1995. 'Sequence analysis', in *Annual Review of Sociology* 21:93–113.

Abbott, Andrew. 2001. *Time Matters. On Theory and Method*. Chicago: University of Chicago Press.

Abell, Peter. 1993. 'Some aspects of narrative method', in *Journal of Mathematical Sociology* 18:93–134.

Arthur, Brian. 1994. *Increasing Returns and Path Dependence in the Economy*. Ann Arbor: University of Michigan Press.

Bailer-Jones, Danjela M. 2002. 'Models, metaphors and analogies', in Peter Magnani and Michael Silberstein (eds), *The Blackwell Guide to the Philosophy of Science*. Malden: Blackwell. 108–27.

Barth, Fredrik. 1995. 'Other knowledge and other ways of knowing', in *Journal of Anthropological Research* 51:65–8.

Bates, Robert H., Avner Greif, Margaret Levi, Jean-Laurent Rosenthal and Barry R. Weingast. 1998. *Analytical Narratives*. Princeton: Princeton University Press.

Bauer, Henry H. 1990. 'Barriers against interdisciplinarity: Implications for Studies of Science, Technology, and Society', in *Science, Technology & Human Values* 15 (1):105–19.

Black, Max. 1993. 'More about metaphor', in Andrew Ortony, *Metaphor and Thought*. Cambridge: Cambridge University Press. 19–41.

Bourdieu, Pierre. 1988. *Homo Academicus*. Stanford: Stanford University Press.

Brüning, R. and Lohmann G. 1999. 'Charles S. Peirce on creative metaphors: A case study on the conveyor belt metaphor in Oceanography', in *Foundations of Science* 4 (3):389–403.

Canguilhem, Georges. 1984. *Wissenschaftsgeschichte und Epistemologie*. Frankfurt: Suhrkamp.

Coase, Ronald H. 1990. *The Firm, the Market, and the Law*. Chicago: University of Chicago Press.

Collier, Rugh B. and David Collier. 1991. *Shaping the Political Arena: Critical Junctures, the Labor Movement, and Regime Dynamics in Latin America*. Princeton: Princeton University Press.

Darden, Lindley. 2002. 'Strategies for discovering mechanisms: schema instantiation, modular subassembly, forward/backward chaining', in *Philosophy of Science* 69:S354–S365.

David, Paul A. 1985. 'Clio and the economics of QWERTY', in *American Economic Review* 75:332–7.

David, Paul A. 1994. 'Why are institutions the "carriers of history"?: path dependence and the evolution of conventions, organizations and institutions', in *Structural Change and Economic Dynamics* 5:205–20.

Dunbar, Kevin. 1995. 'How scientists really reason: scientific reasoning in real-world laboratories', in Robert J. Sternberg and Janet E. Davidson (eds), *The Nature of Insight*. Cambridge: MIT-Press. 365–95.

Eldredge, Niles and Stephen J. Gould. 1972. 'Punctuated equilibria: an alternative to phyletic gradualism', in T.J.M. Schopf (ed.), *Models in Paleobiology*. San Francisco: Freeman, Cooper and Co. 82–115.

Fearon, James D. 1991. 'Counterfactuals and hypothesis testing in political science', in *World Politics* 43:169–95.

Fergunson, Niall (ed.). 1997. *Virtual History: Alternatives and Counterfactuals*. Basingstoke: Macmillan.

Fifth, Raymond. 1992. 'A future for social anthropology', in Sandra Williams (ed.), *Contemporary Futures*. London: Routledge. 208–24.

Fowles, Jib. 1974. 'Chronocentrism', in *Futures* 6 (1):65–8.

Galison, Peter. 1997. *Image and Logic: A Material Culture of Microphysics*. Chicago: Chicago University Press.

Galison, Peter. Forthcoming. *Theory Machines*.

Gould, Stephen J. 1988. *Time's Arrow/Time's Cycle: Myth and Metaphor in the Discovery of Geological Time*. Harvard: Harvard University Press.

Gould, Stephen J. 2002. *The Structure of Evolutionary Theory*. Cambridge: Belknap.

Hammerstein, Peter. 2003. *Genetic and Cultural Evolution of Cooperation*. Cambridge: MIT Press.

Hawthorn, Geoffrey. 1991. *Plausible Worlds: Possibility and Understanding in History and the Social Sciences*. New York: Cambridge University Press.

Heise, David R. 1989. 'Modelling event structures', in *Journal of Mathematical Sociology* 14:139–69.

Kellert, Stephen H. 2000. 'Extrascientific use of physics: the case of nonlinear dynamics and legal theory', in *Philosophy of Science* 68 (3):S455–S466.

Klein, Julie Thompson. 1996. *Crossing Boundaries: Knowledge, Disciplinarities, and Interdisciplinarities*. Charlottesville: University Press of Virginia.

Leigh Star, Susan and James R. Griesemer. 1989. 'Institutional ecology, "translations" and boundary objects: amateurs and professionals in Berkeley's Musum of Vertebrate Zoology, 1907–39', in *Social Studies of Science* 19:387–420.

Löwy, Ilana. 1992. 'The strength of loose concepts – boundary concepts, federative experimental strategies and disciplinary growth: The case of immunology', in *History of Science* 30 (4):371–96.

Mahoney, James. 2000. 'Path Dependence in Historical Sociology', in *Theory and Society* 29:507–48.

Mayntz, Renate. 1990. 'Naturwissenschaftliche Modelle, soziologische Theorie und das Mikro-Makro-Problem', in Wolfgang Zapf (ed.), *Die Modernisierung moderner Gesellschaften. Verhandlungen des 25. Deutschen Soziologentages in Frankfurt am Main 1990*. Frankfurt: Campus. 55–68.

McDonald, Terrence J. (ed.). 1996. *The Historic Turn in the Human Sciences*. Ann Arbor: University of Michigan Press.

Meheus, Joke and Thomas Nickles. 1999. 'The methodological study of creativity and discovery: Some background', in *Foundations of Science* 4 (3):231–5.

Morgan, Mary S. and Margaret Morrison. 1999. *Models as Metaphors. Perspectives on Natural and Social Sciences*. Cambridge: Cambridge University Press.

Nisbet, Robert A. 1969. *Social Change and History. Aspects of the Western Theory of Development*. Oxford: Oxford University Press.

North, Douglas. 1994. 'Economic performance through time', in *American Economic Review* 84 (3):359–68.

Ortony, Andrew. 1993. *Metaphor and Thought*. Cambridge: Cambridge University Press.

Pantin, Carl F.A. 1968. *The Relations between the Sciences*. Cambridge: Cambridge University Press.

Prigogine, Ilya. 1997. *The End of Certainty: Time, Chaos and the New Laws of Nature*. New York: The Free Press.

Ragin, Charles. 1998. 'The logic of qualitative comparative analysis', in *International Journal of Social History* 43 (6):105–25.

Rebaglia, Alberta. 1999. 'Scientific discovery: between incommensurability of paradigms and historical continuity', in *Foundations of Science* 4 (3):337–55.

Rostow, Walt W. 1991 (1960). *The Stages of Growth: An Anti-Communist Manifesto*. Cambridge: Cambridge University Press.

Segerstrale, Ullica. 2001. *Defenders of the Truth: The Sociobiology Debate*. Oxford: Oxford University Press.

Sewell, William H. 1996. 'Three temporalities: Toward an eventful sociology', in Terrence J. McDonald (ed.), *The Historic Turn in the Human Sciences*. Ann Arbor: University of Michigan Press. 245–80.

Steward, Julian Haynes. 1955. *Theory of Culture Change: The Methodology of Multilinear Evolution*. Urbana: University of Illinois Press.

Tetlock, Philip E. and Aaron Belkin (eds). 1996. *Counterfactual Thought Experiments in World Politics: Logical, Methodological, and Psychological Perspectives*. Princeton: Princeton University Press.

Thelen, Kathrin. 1999. 'Historical institutionalism in comparative politics', in *The Annual Review of Political Science* 2:369–404.

Urry, John. 2004. 'Small worlds and the new "social physics" ', in Global Networks 4 (2):109–30.

Wallerstein, Immanuel. 1996. *Open the Social Sciences: Report of the Gulbenkian Commission on the Restructuring of the Social Sciences*. Stanford: Stanford University Press.

Watts, Duncan. 2004. 'The "new" science of networks,' in *Annual Review of Sociology* 30: 243–70.
Wimmer, Andreas. 1996. 'Kultur Reflexionem über einen ethnologischen Grundbegriff,' *Zeitschrift für Ethnologie* 48 (3): 401–25.
Zapf, Wolfgang. 1996. 'Die Modernisierungstheorie und unterschiedliche Pfade der gesellschaftlichen Entwicklung', in *Leviathan* 42 (1):63–77.

Index