Understanding Change

Models, Methodologies, and Metaphors

Edited by

Andreas Wimmer and Reinhart Kössler

Understanding Change

Also by Andreas Wimmer

FACING ETHNIC CONFLICTS. TOWARDS A NEW REALISM (*co-edited*)
DIE KOMPLEXE GESELLSCHAFT. EINE THEORIENKRITIK AM BEISPIEL DES INDIANISCHEN BAUERNTUMS
NATIONALIST EXCLUSION AND ETHNIC CONFLICTS. SHADOWS OF MODERNITY
TRANSFORMATIONEN. SOZIALER WANDEL IM INDIANISCHEN MITTELAMERIKA

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For Yehuda
All good wishes
Andreas

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and

Reinhart Kössler

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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 Institute 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 meta-theory, 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