# Between Chance and Choice

## Interdisciplinary Perspectives on Determinism

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Harald Atmanspacher
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# Preface

**Harald Atmanspacher and Robert Bishop**

Are choice and free will possible in a world governed by deterministic fundamental equations? What sense would determinism make if many events and processes in the world seem to be governed by chance? These and other questions emphasize the fact that chance and choice are two leading actors on stage whenever issues of determinism are under discussion.

The machine sculpture “Klamauk” (English: hubbub) by the Swiss artist Jean Tinguely (1925–1991), featured on the cover, looks like a perfect example of a deterministic process, but it also looks as if thrown together “by chance”. This tension between determinism and chance has been of longstanding concern in the sciences and the humanities. And nowhere is this tension stronger than in debates about free will and our place in the world, where determinism seems bound to crowd freedom out of the picture, yet freedom in the absence of some ordered realm of causes seems inconceivable.

The desire to foster an interdisciplinary dialogue on determinism, chance and free will was the initial impetus leading to an international workshop on determinism taking place at Ringberg Castle near Lake Tegernsee, south of Munich, in June 2001. Representatives from mathematics, physics, cognitive and social science, and various branches of philosophy convened to discuss numerous aspects of determinism from their disciplinary perspectives. This volume is based on elaborated and refereed manuscripts of their lectures.

The contributions by Bishop and Nickel form an introduction to the topics discussed in the volume, focusing on aspects of determinism as they arise in mathematics, physics, psychology, and philosophy. These essays discuss characteristics for determinism in these fields as well as bring out the clash between the deterministic perspective of the natural sciences and the phenomenological perspective of lived experience. It is suggested that this clash may be eased through broadening our notions of causation and by realizing that the scientific and every day views are particular perspectives, among many possible ones, from which we may analyze or understand our world.

The first principle subdivision of the volume mainly is devoted to the relation between determinism and chance. Atmanspacher in his contribution distinguishes between determinism and determinability using a distinction between ontic and epistemic states in physical descriptions. Lombardi, using this same distinction, addresses Putnam's notion of internal realism in the context of physics, arguing that there is no single, pre-given ontology because the questions we ask, both theoretical and experimental, "cut into" reality in a way determining much of the chosen ontology. What is ontic and what is epistemic depends on the questions scientists ask.

Primas and Gustafson discuss results on embedding descriptions of stochastic processes into larger deterministic descriptions. One important feature of these results, according to Gustafson, is that any innovation process, i.e. process losing information as it proceeds forward in time, cannot be time-reversed. Primas refers to embedding theorems as providing a "hidden" determinism in physics and discusses this determinism in relation to the free actions of scientists. Both authors agree that the meaning of the embedding results for the reality of determinism is unclear.

In a related contribution, Misra shows how it is possible to move from a deterministic evolution to an irreversible probabilistic process via a mathematical transformation between the two types of descriptions. This approach shows most clearly that the distinction between determinism and chance for a wide class of systems can be conceived as a matter of description rather than an ontological issue.

Christidis, Kronz and McLaughlin, Dieks, and Berkovitz address chance and determinism from historical and philosophical viewpoints. Christidis interprets some of the fragments of Heraclitus as early precursors of guiding ideas in work by Prigogine and his colleagues. Kronz and McLaughlin discuss Peirce's evolutionary cosmology, where the universe starts out indeterministically and becomes increasingly deterministic by "habituation". Dieks raises questions regarding some implications of physical indeterminism for our ordinary language concepts such as novelty and openness of the future. Berkovitz's contribution examines the roles of determinism and indeterminism as assumptions in causal models using examples from economics.

This first subdivision ends with two papers discussing different aspects of control. Mahler and colleagues show that in the context of quantum mechanics the irreversibility connected with the increase of entropy is associated with a set of robust macro-level (thermodynamic) properties enabling various types of large-scale prediction and control of systems even as prediction and control of the micro-level (statistical) properties are progressively lost. Greenberger and Svozil discuss the consistency requirements for the prediction and control of events and apply them to a quantum mechanical model for time travel.

The second subdivision addresses determinism and free will. Dowe's contribution compares the folk notion of determinism with standard approaches to determinism based on science and discusses causation as a folk notion. Guignon sets out to dissolve the problem of reconciling free will with determinism by questioning the very framework within which the problem is formulated. He explores the realm of human action as a holistic, meaning-filled, embodied lifeworld, where we are always already engaging the world around us in practical ways.

Dorato defends a compatibilist view of free will, focusing on conceptual and pragmatic issues of the debate between compatibilists and incompatibilists. Kane defends an incompatibilist view of free will, invoking a novel indeterministic strategy, and responds to Dorato's discussion of his view in this volume. Martin and Sugarman, working within a broadly compatibilist framework, discuss a developmental account of agency. Richardson and Bishop, in the context of the social sciences, examine and call into question various assumptions shared by both compatibilist and incompatibilist accounts of free will.

Psychology takes center stage in the contributions by Gantt and Slife. Gantt discusses the problems of a reductive biologization in psychology and proposes phenomenological alternatives treating our lived experience as primary for understanding action, meaning, morality, etc. Slife questions the role that atomistic conceptions of time and information have played in psychological theories and proposes holistic alternatives that make better sense of how our view of the past, present and future shape our current actions and vice verse. In the final contribution in this subdivision, Abe and Kobayashi discuss Eastern views of determinism, and compare and reinterpret them from a scientific point of view.

Ringberg Castle is operated as a conference center of the Max Planck Society, whose hospitality is gratefully acknowledged. In particular we would like to thank Axel Hörmann and the staff of the center for their help in matters large and small ensuring the success of this workshop. The Institut für Grenzgebiete der Psychologie und Psychohygiene (IGPP) at Freiburg supported both the workshop and this volume financially. Keith Sutherland (Imprint Academic) provided competent advice for the smooth and fast publication of the volume. Finally we would like to thank Gundel Jaeger (IGPP) for a terrific job on conference pre-arangements and in preparing the manuscripts.

# Deterministic and Indeterministic Descriptions

**Robert C. Bishop**

**Abstract**

In the practice of physics, a very general and precise description of a deterministic process in terms of group or semigroup operators can be given, characterized by three crucial properties: differential dynamics, unique evolution and value determinateness. In contrast quantum mechanics offers some models for indeterministic processes, but an analogous general description of indeterministic physical processes is lacking. It is clear that one of the elements of an indeterministic description is that it should be expressed in terms of semigroup operators, since indeterministic processes are time irreversible. What other elements are necessary and sufficient to qualify a description as indeterministic remain unclarified, however. In the practice of human sciences such as psychology, on the other hand, general forms of deterministic or indeterministic descriptions are not well developed. Some difficulties for developing general yet precise deterministic and indeterministic descriptions focusing specifically on psychology are explored.

## 1 Introduction

Determinism is often thought of as a metaphysical doctrine about our world. I am not going to address the truth or falsity, or even the applicability, of such a doctrine here, except with a few comments at the end. Rather, I want to focus on the general characteristics of deterministic and indeterministic descriptions. That is to say, I want to explore the properties that make particular theories or models about systems in our world deterministic or indeterministic. Although the properties making a description of a physical system deterministic can be identified rather easily, identifying the corresponding properties that make a description of a physical system indeterministic with precision is not so easy. And when we turn to the question of properties making descriptions in human sciences, such as psychology, deterministic or indeterministic, things become even murkier and more complicated.

## 2 Deterministic Descriptions in Physics

Let me begin with a distinction that is immediately relevant to physical descriptions, namely the ontic/epistemic distinction. This distinction is applied to states and properties of a physical system. Roughly, ontic states and properties refer to features of physical systems as they are "when nobody is looking," while epistemic states and properties refer to the features of physical systems accessible to empirical observation. Scheibe (1973) first introduced this distinction. It has been subsequently developed in various versions (Primas 1990, 1994; Atmanspacher 1994; d'Espagnat 1994; see also Atmanspacher in this volume). An important special case of ontic states and properties are those that are deterministic and describable in terms of points in an appropriate phase space. An important special case of epistemic states and properties are those that are describable in terms of probability distributions (or density operators) on some appropriate phase space.

A phase space is an abstract space of points where each point represents a possible state of the model. A simple example would be characterizing the possible states of a physical system in terms of its generalized momenta and positions.[1] A model can be studied in phase space by following its trajectory from an initial state $(q_o, p_o)$ to some final state $(q_f, p_f)$ (see Figure 1).

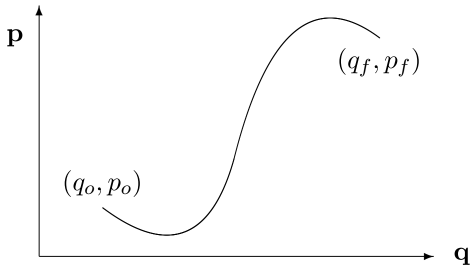


Figure 1: Path of the state of a physical system in phase space.

[1]Using generalized coordinates and momenta allow for systems to be characterized by variables other than linear momentum and position (e.g. angles and angular momentum in the case of a pendulum).

## 2.1 Laplacean Determinism

Clocks, cannon balls fired from cannons and the solar system are taken to be paradigm examples of deterministic systems in classical physics. In the practice of physics, we are able to give a very general and precise description of deterministic systems conceived of ontically. For definiteness I will focus on classical particle mechanics (CPM), which inspired Laplace's famous description of determinism (Laplace 1814/1951, p. 4). Suppose that a state of a system is characterized by the values of the positions and momenta of all the particles composing the system and that a physical state corresponds to a point in phase space through these values. We can then develop mathematical models for the evolution of these points in phase space and such models are taken to represent the physical systems of interest. Three properties have been identified playing a crucial role in such deterministic descriptions expressing Laplace's conception of determinism (Stone 1989; Kellert 1993; Bishop 1999, chap. 2):

(DD) Differential Dynamics: An algorithm relates a state of a system at any given time to a state at any other time and the algorithm is not probabilistic.

(UE) Unique Evolution: A given state is always followed (preceded) by the same history of state transitions.

(DD) Value Determinateness: Any state can be described with arbitrarily small (nonzero) error.

Differential dynamics is motivated by actual physical theories expressed in terms of mathematical equations. These equations, along with their initial and boundary conditions, are required to be nonprobabilistic. This requirement expresses the Laplacean belief that CPM contains no indeterministic elements like those present in some versions of quantum mechanics. Such equations describe the individual trajectories of ontic states in phase space.

Unique evolution is closely associated with DD. It expresses the Laplacean belief that CPM systems will repeat exactly the same trajectory if the same initial and boundary conditions are specified (cf. Nickel's formal characterization in his contribution in this volume). For example the equations of motion for a frictionless pendulum will produce the same solution for the motion as long as the same initial velocity and initial position are chosen. Roughly, the idea is that every time we return the mathematical model to the same initial state, it will undergo the same history of transitions from state to state. In other words the evolution of the model will be unique with respect to a particular specification of the initial and boundary conditions. Furthermore we can choose any state in the history of state transitions as the initial starting point and the model's history will remain unchanged.

Although a strong requirement, UE is important if physical determinism is to be a meaningful concept. Imagine a typical model $m$ as a film. Unique evolution means that if we were to start the film over and over at the same frame (returning the model to the same initial state), then $m$ would repeat every detail of its total history, and identical copies of the film would produce the same sequence of pictures. So no matter whether we always start *Jurassic Park* at the beginning frame, the middle frame or any other frame, it plays the same. No new frames are added to the movie nor is the sequence of the frames changed simply by starting it at an arbitrary frame.

By contrast, suppose that returning $m$ to the same initial state produced a different sequence of state transitions on some of the runs. Consider a model $m$ to be like a computer that generates a different sequence of pictures on some occasions when starting from the same initial picture. Imagine further that such a model has the property that simply by starting with any picture normally appearing in the sequence, it is sometimes the case that the chosen picture is not followed by the usual sequence of pictures or that some pictures often do not appear in the sequence or that new ones are added from time to time. Such a model would fail to have unique evolution.

Value determinateness is motivated by the Laplacean belief that there is nothing *in principle* in CPM preventing mathematical descriptions of arbitrary accuracy. For example the models of CPM all presuppose precise values for the constants and variables used in the equations of motion. This, again, is consistent with the description of ontic states having precise, definite values. Glymour (1971, pp. 744–745) takes value determinateness as one of the necessary criteria for determinism and cites Peirce and Reichenbach as examples of philosophers who have included this criterion in their analyses of determinism. Since CPM is often taken as the paradigm example of a deterministic theory, it is natural that value determinateness would come to be seen as part of the Laplacean vision for classical physics. It is only with the advent of quantum mechanics that questions were raised about the applicability of value determinateness to all of physics.[2]

The three properties of Laplacean determinism can easily be related to the types of group and semigroup operators used in various physical theories

[2]Historically a fourth property known as absolute predictability completed the picture of determinism as conceived by Laplace, but the relationship of predictability to determinism is more subtle than typically realized and the type of predictability implied by DD, UE and VD is also much weaker than often conceived (Bishop 1999, chap. 2).

(Bishop 1999, pp. 30–32; see also Nickel in this volume).[3] First, as the source for the equations of motion of CPM, such operators give a precise prescription for how to go from one state of the system to another (DD). Second, the phase space trajectory governed by these operators remains unique no matter what state in the trajectory's history is chosen as the initial state (UE). Third, the operators and the resulting equations of motion operate on determinate values as exhibited by the uniqueness and existence theorems for the differential equations of CPM (VD). Thus group and semigroup operators yield a precise, nonvacuous realization of the properties DD, UE and VD of deterministic descriptions.

## 3 Towards an Indeterministic Description in Physics

According to the ontic/epistemic distinction, indeterministic descriptions are typically associated with epistemic properties of physical systems; that is to say, properties accessible to observation (e.g. a system interacting with a measuring apparatus). The question naturally arises as to whether there can be an ontic description of a physical system that is fundamentally indeterministic.

Although the example of the computer that did not always display the same sequence of pictures even if we always started with the identical first picture looks on the surface to be a candidate indeterministic system, the paradigm examples for indeterministic physical systems are found in quantum mechanics (e.g. radioactive decay). So let me give a simple illustration of quantum mechanics. In our everyday world, stop lights operate with a predictable sequential pattern of green, followed by yellow followed by red. To get a sense for how different the quantum realm is, suppose quantum stop lights have two possible sequential patterns: either green, yellow, red, or green, red, yellow. Furthermore suppose we keep the standard meaning for the three colors: Green means go, yellow means caution, red means stop.

Suppose that observations show quantum stop lights have a probability of 50% for exhibiting the green-yellow-red pattern and of 50% for exhibiting the green-red-yellow pattern. Let me emphasize that the probability refers

[3] A group of operators differs from a semigroup of operators in that the former includes inverse elements lacking in the latter. This can be thought of in the following way: Group operators describe physical processes that can go forwards and backwards in time whereas semigroup operators describe processes going in one temporal direction.

to the patterns and not to the appearance of any individual color.[4] If the light is red when you approach the intersection, there is no problem. You simply stop and wait. If the light is green while you approach, it could turn red any moment. But if you were approaching a quantum stop light that was currently yellow, you would not know if the light was going to turn red or green next, because you would not know what pattern the light was exhibiting. You could observe the quantum stop light over a long period of time to determine probabilities for the two patterns. But you have no way of knowing *in advance* which pattern the light will exhibit as you come to the intersection, because the patterns at the level of observation are indeterministic; that is, we cannot say with certainty in which pattern we will find a quantum stop light on any given approach to an intersection.

We have observed that there is a 50% probability for each pattern to be exhibited by a quantum stop light. How are we to understand the nature of this probability? One possibility is that there is some additional factor, a hidden mechanism, such that once we discover and understand this mechanism, we would be able to predict the observed behavior of the quantum stop light with certainty (physicists call such an approach "hidden variable theory"). Or perhaps there is an interaction with the broader environment (the trees and buildings surrounding the intersection, say) that we have not taken into account in our observations and which explains how these probabilities arise (physicists call such an approach "decoherence"). In either one of these scenarios, we would interpret the observed indeterministic behavior of the stop light as an expression of our ignorance about the actual workings of the stop light. Under this interpretation indeterminism would not be a fundamental feature of the quantum stop light, but merely *epistemic* in nature due to our lack of knowledge about the system. Quantum stop lights would turn out to be deterministic from an ontic point of view.

The alternative possibility is that the indeterministic behavior of a quantum stop light is *ontic*, i.e. all the relevant factors do not fully determine which pattern the stop light is going to exhibit at any given moment.[5]

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[4]For those who know some quantum mechanics, the patterns of the quantum stop lights are analogous to a two-state system. The green-yellow-red pattern would be an up state and the green-red-yellow pattern would be a down state. Approaching the intersection would be analogous to a measurement on the system.

[5]I have presented these possibilities for understanding the behavior of a quantum stop light in a simplified manner. The basic physical states must be described as a superposition of probability amplitudes, each probability corresponding to a particular outcome or pattern. On some construals of quantum mechanics, measurements do not require a superposition of probabilities to indeterministically collapse to one outcome. Then such

It would be helpful if physics had a general description of indeterministic systems available where the key properties making a system indeterministic could be identified as in the case of deterministic descriptions described in section 2. This is not the case, however. Nevertheless, one might begin developing the general features of such an indeterministic description by modifying the properties of a deterministic description (DD, UE and VD).

## 3.1 Value Determinateness

Suppose we begin by dropping VD. If one thinks that determinateness and determinism are closely related – as Glymour (1971) suggests – then dropping VD would guarantee indeterminism in a physical description. Although value determinateness applies to CPM, according to many construals of quantum mechanics physical variables do not have sharp or definite values. The technical results of interest are the Bell inequalities (Bell 1987) and the Kochen-Specker theorem (Kochen and Specker 1967): Given the formalism of quantum mechanics, the assumption of 1) locality (motivated by special relativity) and 2) definite physical values leads to contradictions.[6] In the face of problems raised by Bell for locality, and by Kochen and Specker for contextualism and locality, however, it is possible to revise determinism to allow for set- and interval-valued properties evolving along uniquely determined paths (Fine 1971; Teller 1979; Earman 1986, pp. 217–218).[7] Dropping VD, then, is not sufficient to guarantee an indeterministic description.

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systems would behave deterministically. On other construals, there is an indeterministic collapse that would lead to indeterministic behavior in such systems. This implies that for chaotic systems, due to sensitive dependence, there may be cases where different interpretations or theories of quantum mechanics make a difference in the behavior of the chaotic macroscopic system, raising questions about whether such chaotic systems are deterministic or not (Bishop and Kronz 1999). Some implications of such questions for free will theories based on chaotic brain states amplifying quantum fluctuations (e.g. Kane 1996) are discussed by Bishop (2002a) and Kane (this volume).

[6] The locality requirement implies there is no backwards-in-time causation or violations of special relativity. The Kochen-Specker theorem requires contextualism as an additional assumption.

[7] If one is willing to consider *nonlocal* hidden-variable theories that do not violate special relativity (e.g. Bohm's quantum theory (1952a,b)), then value determinateness can be made consistent with quantum mechanics. The results of the local no hidden-variables theorems of Bell, and Kochen and Specker do not hold if the assumption of locality is dropped. Since the analysis of measurements is no more problematic for such interpretations of quantum mechanics than for local ones, these proposals represent viable alternatives for maintaining VD as a necessary property for a description of determinism even at the quantum level (depending on one's view of the measurement problem).

### 3.2 Differential Dynamics

Suppose we drop DD, thus allowing our equations to make explicit references to probability. Simply relaxing this restriction is not sufficient to render a model composed of such equations indeterministic, however. For example Schrödinger's equation in quantum mechanics describes the evolution of probability amplitudes, but this evolution is strictly deterministic: Given a wave function representing a superposition of probability amplitudes and the same initial and boundary conditions, the wave function will evolve the same way under repeated applications of Schrödinger's equation in analogy with a film. Actual terms in our model equations will have to be probabilistic, and/or the initial or boundary conditions will have to be probabilistic.

It turns out, nonetheless, that even requiring probabilistic terms and/or probabilistic initial and boundary conditions will not be sufficient to render a mathematical description indeterministic. For, as Gustafson and collaborators have demonstrated, many types of probabilistic descriptions of processes can be embedded within larger deterministic descriptions (Gustafson and Goodrich 1980, Antoniou and Gustafson 1993, Gustafson 1997; see also Gustafson's contribution in this volume). So we still face a fundamental question: What is the nature of the probabilities involved? Are they due to mere ignorance of underlying deterministic processes or are they irreducible to such processes? In other words we still need to know whether the probabilities are epistemic or ontic, but this is precisely the job we want our eventual criteria for indeterministic descriptions to do. It may be possible in particular instances to argue that a probability is irreducible to any deterministic processes as, for example, in the case of recent work by Prigogine and his Brussels-Austin colleagues (cf. Atmanspacher et al. 2001, p. 63–67; Bishop 2002b), but that is not the same as having some general properties characterizing indeterministic descriptions.

### 3.3 Unique Evolution

What about dropping UE? Kellert (1993, pp. 69–75) argues that UE can be separated from determinism because chaotic systems can amplify quantum fluctuations due to sensitive dependence (cf. Hobbs 1991, p. 157). Briefly, the reasoning runs as follows. Given two chaotic systems of CPM in nearly identical initial states (e.g. initial positions and velocities), they will evolve in radically different ways as the slight differences in initial conditions are amplified exponentially. There is no known lower limit to this sensitivity, thus, nothing prevents the possibility of chaotic macroscopic systems from being sensitive to quantum fluctuations. Quantum mechanics would then set a lower bound on how precisely the initial conditions can be specified. Hence UE must fail for chaotic CPM models.

However, these kinds of sensitivity arguments depend crucially on how quantum mechanics itself and measurements are interpreted as in the case of the quantum stop light (Bishop 1999, chap. 3; Bishop and Kronz 1999, pp. 134–138). Furthermore, although abstract sensitivity arguments do correctly lead to the conclusion that the smallest effects can be amplified, applying such arguments to concrete physical systems shows that the amplification process may be severely constrained. For example investigating the role of quantum effects in the process of friction in sliding surfaces indicates quantum effects can be amplified by chaos to produce a difference in macroscopic behavior only if the fluctuations are large enough to break molecular bonds and are amplified quickly enough (Bishop 1999, pp. 82–86).

As suggested by comparing the examples of a film that plays the same on each run with a computer that shows different pictures on each run, UE is significant for any conception of determinism. But would dropping UE yield indeterminism? To find out we need to see whether it is possible to drop UE and get indeterminism purely from an evolution equation. According to van Fraassen, we can build a set of "indeterministic counterparts" to the group and semigroup operators mentioned above. Let $S$ be a subset of the phase space and $b$ a positive number. Then (van Fraassen 1991, p. 51)

$T_b(S) = \{x$ : for some possible* trajectory $u$, time $t$, and some state $y$ in $S$, $u(t) = y$ and $u(t+b) = x\}$;

$T_b^\dagger(S) = \{y$ : for some possible* trajectory $u$, time $t$, and some state $x$ in $S$, $u(t) = y$ and $u(t+b) = x\}$,

where a trajectory $u(t)$ is possible* relative to $v(t)$ exactly when $u(t) = v(t)$ for all $t \leq t_1$. The trajectories $u(t)$ and $v(t)$ may disagree for all $t > t_1$ (Fig. 2). Obviously, $T_b T_b^\dagger(S)$ *does not* return to the original state in $S$. Furthermore these operators require a change in the notion of possibility from the standard one used in groups and semigroups. The operators $T$ yield a phase space structure defining a set of possible* trajectories that can be continuations beyond time $t_1$. Both $u$ and $v$ are possible continuants, but no one is guaranteed to be *the* continuant. Thus unique evolution is lost with no explicit introduction of probability into any equations (DD can be fully preserved).

Another observation is that the operators $T$ must form a semigroup of operators (so there are no inverse operators). Suppose that we start at some point $p(t_o)$ and apply $T_b$. This operation would be equivalent to tracing out

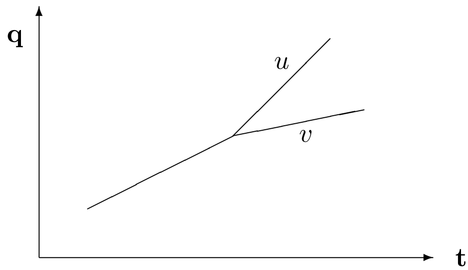


Figure 2: Two possible continuants $u$ and $v$ of a trajectory, agreeing over part of their history, then diverging at some point in time.

a trajectory from the point $p(t_o)$ to the point $p(t_o+b)$. There is no guarantee that applying $T_{-b}$ to $p(t_o+b)$ would retrace the trajectory back to the original point $p(t_o)$, because there are any number of possible continuants and no one of them is guaranteed on any given application of an operator $T_{-b}$ (in Figure 2, suppose that the application of $T_b$ traces out the trajectory $u$ ending at $p(t_o+b)$, and that the application of $T_{-b}$ traces out the inverse of $v$ starting at point $p(t_o+b)$). Furthermore the operators $T$ obey the semigroup property $T_bT_c = T_{b+c}$, though there is no guarantee that applying $T_{b+c}$ to the same point $p(t_o)$ will yield the same trajectory because there are many possible* continuants.[8]

The structure defined by $T$ on the phase space is clearly indeterministic. It is too weak, however, to generate an adequately informative theory. The theory generated by $T$ tells us what possible continuants $u(t)$ has for times greater than $t_1$, but it does not make any assignments for how probable any of the possible continuants are. Suppose the theory generated by $T$ tells us that, given an initial state, a model of $T$ will evolve through various indeterministic branching points (analogous to a computer that can produce a different sequence of pictures on each run). Unless the evolution equation for the model gives the probabilities for following the various branching points, we have no more information from our theory than that it is indeterministic. Strictly speaking, then, the loss of UE does not imply that the evolution equation be explicitly probabilistic, but in order to have much *intelligible* to

[8]This feature is related to an argument by Reichenbach (1956, p. 211) that the assumption of time-reversibility and indeterminism yields a contradiction. Presumably for indeterminism to be true, the evolution from $p(t_o)$ to $p(t_o+b)$ must be unreliable in the sense that $p(t_o+b)$ can be any arbitrary point allowable on the phase space. Time-reversibility, in contrast, requires reliable evolution between $p(t_o)$ and $p(t_o+b)$ in both temporal directions.

say other than the model is indeterministic, an explicitly probabilistic prescription seems required, forcing us to drop DD in tandem with dropping UE in order to have a theory that is precise enough for calculation purposes.

One can object to the way I have used the term "indeterministic" in the previous paragraph. For example there are physical systems known as *Kolmogorov flows*, or K-flows, having the defining property that the current state plus the entire past history of state transitions is insufficient to fix or determine the next state transition from a statistical or coarse-grained perspective. Which is to say that if we were to divide the phase space into small squares of area $\alpha$, no matter how small we make $\alpha$, the trajectory will jump to the next state in such a way that we cannot determine with probability one (complete certainty) what that next state will be. We can, of course, recover a deterministic description for K-flows in the limit where $\alpha$ is zero and we focus on individual trajectories and states of the system. But from the coarse-grained perspective, K-flows behave just like the description of the theory $T$ sketched in the preceding paragraph. This suggests that the nature of the probability in such descriptions is crucial to the question of indeterminism.

Another possible problem for the operators T is that the notion of possible* is a philosopher's notion. It is not clear at all if or how we are to mathematize such a notion so that it becomes precise enough to use in an indeterministic description. One might hope that the lack of informativeness problem I just described can be overcome by an appropriate mathematical formulation of this notion of possibility. Unfortunately none seems to be available at the moment.

## 3.4 Taking Stock

Provisionally, the modified set of properties of an indeterministic description might take the following form:

(DD*) An algorithm relates a state of a system at any given time to a state at any other time (possibly) probabilistically.

(UE*) A given state may be followed (preceded) by the same history of state transitions.

(VD*) Any state may be described with determinate values.

(P*) Probabilities must be irreducible to the trajectories of individual states.

As indicated above, modifying UE in the fashion suggested appears to necessitate modifying DD and VD as well, though modifying either DD or VD alone does not imply that UE must be modified. Furthermore the semigroup $T$ exhibits the properties DD*, UE* and VD*.

Yet things are still too vague in two respects. First the semigroup $T$, though suggestive, is not mathematically precise enough for calculations. Second the nature – ontic or epistemic – of the probability invoked in DD* remains unclarified. Property P* is an attempt to clarify a minimal requirement for indeterminism. The intuition is that the probabilities arising in indeterministic processes cannot be reduced to or redescribed in terms of the trajectories of individual states (e.g. Bishop 2002b). For example the conventional approach to describing physical systems within CPM relies on a representation of states (e.g. of particles) as points in an appropriate phase space (recall Figure 1). This means that the dynamics of a system are derived using particle trajectories as a fundamental explanatory element of its models (provided the states of the systems are parametrized by time). When there are too many states involved to make these types of calculations feasible (as in gases or liquids), coarse-grained averages are used to develop a statistical picture of how the system behaves rather than focusing on the behavior of individual states. Nevertheless the individual states remain ontically primary in these descriptions (recall the discussion of K-flows above).

In contrast the probabilities having property P* are such that the behavior of the system is no longer governed by the dynamics of individual states, but by the probability distributions (or density operators) themselves. Hence the probability distributions are the fundamental explanatory elements and so are to be conceived as ontic rather than merely epistemic. Though these intuitions suggest some possible directions for further research, much work remains to clarify this notion of probability.

In summary then, if we are willing, for the moment, to forgo full mathematical precision, the key property defining an indeterministic description has been identified as UE*. It implies that the identical initial state at $t_o$ plus the evolution equations would be *insufficient* to specify the same state at a later time $t_i$, clearly rendering the description indeterministic (for technical examples in CPM, see Earman 1986, Bishop and Kronz 1999, Xia 1992). To say anything mathematically precise in terms of a condition distinguishing indeterministic from deterministic descriptions runs into an interpretive question regarding the nature of the probability involved.

The obvious move here is to examine the physical process being modeled as to whether it is indeterministic, hence, removing the ambiguity. However, this simply moves the interpretive question back one more step in the sense that the probabilistic process we observe (say in a quantum stop light) can be interpreted ontically or epistemically. Not surprisingly our observations underdetermine these possibilities. One could appeal to the embedding results I mentioned above: Under fairly general conditions, probabilistic descriptions can be transformed into deterministic descriptions by embedding them within a larger deterministic system. However, since these results are also at the level of our descriptions, they do not settle the issue of whether a physical process is deterministic or not. After all, simply transforming an indeterministic description mathematically into a deterministic one says nothing about the nature of the physical process we are investigating.[9] So it appears that we cannot read determinism out of our best physical theories or our observations in some unambiguous way.

Ultimately, wether we interpret a physical process as being deterministic or indeterministic derives from our metaphysical commitments regarding determinism. If we are metaphysical determinists, then naturally we will read the probability expressed in P* as ultimately a measure of our ignorance about the underlying determinism. If we do not make any metaphysical presuppositions regarding determinism, then we read conditions like P* with an empirical attitude towards our experiments and best theories. We do not have to understand them as implying metaphysical determinism.

Methodologically, agnosticism with respect to or denial of metaphysical determinism only means that we do not seek always in the past for the necessary and sufficient reasons for the occurrence of an event (e.g. looking for causes simultaneous to events or even pursuing kinds of formal causation analogous with the influence symmetry principles and conservation laws possess in physics). To be sure metaphysical determinism has provided a framework in which the ontologies underlying physics have been developed, but its experimental methodologies do not necessarily derive any support from metaphysical determinism.[10] However, eliminating those metaphysi-

[9]In his contribution in this volume, Primas refers to the possibility that the larger deterministic systems invoked in such embeddings are fictions.

[10]The development of the doctrine of divine freedom played a crucial role in the historical development of empirical science as a self-sustaining practice. For example, renewed theological emphasis on the contingent nature of creation – i.e. that it could have been otherwise than it is due to divine freedom – flowing out of the condemnation of Averroism in 1277, led to a growing emphasis on the importance of observation and the need for hypotheses and theories to match observed individual facts. The Aristotelian ideal that theories could start with self-evident first principles and proceed by deduction continued to exert strong influence on medieval thinkers, but its grip was slowly loosed. As questions shifted from "How must the world be?" to "What is *this* world like?", a shift suggested by divine freedom in creation, the approaches for answering questions in natural philosophy

cal commitments will have few, if any, substantial effects on the practice of physics.

# 4 Deterministic and Indeterministic Descriptions in Psychology

In the practice of human sciences such as psychology, general forms of deterministic or indeterministic descriptions are not well developed. Determinism, however, plays a crucial role in most personality theories as well as broader theoretical movements in psychology (Slife and Williams 1995, Bishop 2002c). Furthermore determinism in psychology is described in the language of efficient causation, patterned after the physical sciences. Though various approaches within psychology differ in many theoretical aspects, one thing most of them share in common – along with much of the rest of behavioral science – is a belief that the past is causally sufficient to explain present and future behavior; that is to say, past events *determine* present and future behavior. For example taking a history of a patient – i.e. collecting the unique experiences, important life events, parental interactions, etc. – is a standard feature of virtually all therapeutic practice. Although therapists will differ with respect to the emphasis placed on distant versus immediate past events, they almost universally agree that past events are the keys to understanding current behaviors.

## 4.1 Psychological Models of Determinism

I briefly want to explore two different versions of efficient causation and determinism, one or the other of which shape many, if not most, theoretical approaches in psychology at their core.

The first I will call the *physics model*. The idea here is that just as an appropriate accounting of the relevant physical forces enables us to understand the dynamics of some physical process, an appropriate accounting of

had to undergo a corresponding shift. Over time the warrant for hypotheses and theories shifted from a self-evident basis to extrinsic empirical evidence, but this shift did not happen immediately (McMullin 1965, pp. 108–113; Lindberg 1992, pp. 230–244). Theodoric of Freiburg is one of the few medieval examples of a natural philosopher pursuing actual experiments using flasks of water in his studies of refraction models in order to understand rainbows (McMullin 1965, p. 121; Lindberg 1992, p. 253). The use of experiments to answer questions about the world gradually increased through the fourteenth and fifteenth centuries (e.g. Marliani, Cusa, da Vinci), but it was through Galileo that experiment finally took center stage in physics.

the relevant psychological and social forces involved enables us to understand the human behavior in question. For example both psychodynamics and behaviorism exemplify this approach. Human behaviors are explained in terms of the forces producing them (drives and so forth in psychodynamics; stimuli and reinforcement in behaviorism). In the case of psychodynamics, behavior is governed by depth psychological forces in combination with some external social forces. Take the example of a father who never expresses love or praise thereby causing his son to grow up with a set of perfectionist behavior patterns always trying to win the approval of potential father/authority figures. These early childhood dynamics set in motion an internal set of psychological forces operating at an unconscious level in the son that govern his social interactions with both peers and authority figures.

Instead of viewing people as creators of meanings and values, the physics model views them more like electrons responding to forces in a law-like way. For example, behaviorist theory reduces loving to “loving behaviors” which are brought about by environmental forces. So instead of loving being imbued with the meaningfulness, purposive character, and creativity we commonly believe it to have, we simply exhibit loving behaviors because ultimately these behaviors have been shaped or conditioned by brute environmental forces and contingencies. Like electrons, we respond to these external forces in law-like ways and engage in behaviors determined by these forces.

The second model might be called the *computer model*. Here the causal role is not played by forces as in the physics model, but by the rules and structures governing the input-processing-output scheme of the mind and by the nature of the information input into the system (Slife and Williams 1995, pp. 37–45). Consider a word processor. The hardware fixes the basic possibilities for processing while the software provides instructions for the particular types of processing the hardware will carry out. But the information I type (information input) is crucial to the response of the system. For example, if I misspell a word, the program may automatically correct it or place a red line under it to indicate a problem.

Cognitive psychology exemplifies this model with its reliance on the crucial role information input and processing play in explaining behavior. All human behaviors along with motives, intentions, desires, etc. are reduced to information input and the processing of the cognitive apparatus. Returning to the example of the approval-seeking son, the childhood interactions with his father can be viewed as “programming” or “software” providing instructions on how to process new information derived from his social interactions with peers and authority figures.

Instead of viewing people as creators of meanings and values, this model views them more like computers operating according to logical or rational information processing rules. All questions about behavior are reduced to questions about the structure of the cognitive system and the nature of the information input into that system. On the computer model analysis, loving is reduced to information input, representation and cognitive computation. The implication is that loving – indeed all our relationships with other people – is the result of processing information inputs along cost-benefit, Bayesian or other lines of analysis. Again this implies that loving does not have the same meaningfulness and creativity with which we commonly associate it, but, rather, is conditioned on information input and processing.[11]

Note that both these models are mechanistic rather than humanistic in thrust. There is a smaller, diverse, relatively marginal group of humanist, existentialist, or phenomenological thinkers in psychology, who explicitly reject such mechanistic approaches to understanding human agency. But they usually fail to take note of the fact that the realization of their nonmechanistic ideals actually depends upon some reliable connectedness among the events of human experience. Partly for that reason, these psychologists rarely develop any plausible alternative account of this connectedness, and so must still rely on, and are haunted by, the very sort of efficient causal deterministic viewpoint which they reject.

## 4.2 Deterministic Descriptions in Psychology

In a deterministic description of a physical system, we can give precise mathematical formulations of the conditions DD, UE and VD. By contrast, in describing a "psychological system" we have no mathematically precise way to formulate conditions. Standard mathematical tools are not immediately useful for psychological descriptions, in spite of the mechanistic flavor of the physics and computer models of behavior.[12] Nevertheless it is possible to formulate conceptual conditions for a deterministic psychological description.

Taking a cue from the crucial role UE plays in physical deterministic descriptions, let us start by giving the "story line" for the analogous property in the physics and computer models. In the physics model, given the

[11] Some of the philosophical and moral presuppositions and implications of these models are explored by Bishop (2002c); see also the contributions by Gantt, Guignon, Richardson and Bishop, and Slife in this volume for related discussions.

[12] Torretti (2000) has pointed out that the belief that "the really real can be adequately represented as a mathematical structure" represents a return to a Pythagorean prejudice rather than a conclusion derived from scientific practice. We must be careful not to fall prey to this prejudice when thinking about psychology.

identical psychological and social forces along with the identical biological-neurological system ("multiple runs" with "identical initial conditions"), a person would presumably repeat their same behaviors in terms of their life history. That is to say, if we insert the identical person into the identical world with the identical circumstances, they will live an identical life. In the computer model, given the identical cognitive processing apparatus and identical information input, a person would presumably repeat their same behaviors in terms of their life history as well.

Formulated in terms of life histories, it is clear that we have to worry about robustness. For example, are worlds physically identical in their totality required for generating identical life histories for an individual on "multiple runs"? How much physical difference in a given world can be tolerated before that introduces some relevant difference in the psychological/social forces (in the physics model) or the information input and processing (in the computer model) producing behavior changes with respect to a person's behavior in a given control or baseline world? Or suppose that two worlds are identical in every detail except that a girl, say, is born with red hair in one world and blond hair in another. What kinds of changes will result in the social forces or information inputs leading to differences in her behavior?

It is far from clear how to answer these robustness questions for entire life histories, so perhaps we should look at a weaker demand. After all, the requirement that psychological explanations of present behavior be found in the past does not necessarily require determinism in the sense of identical life histories. Robustness in psychological determinants – in a typical counseling situation say – can be understood along the lines of finding significant historical/relational events or patterns that serve as the cause for a person's behavior.

Recall the example of the son and his unaffirming father. The childhood interactions with the unaffirming father form the crucial events that serve to determine the son's behavior in all other circumstances. On the physics model, this is a set of psychological/social forces that are robust in the sense that changes in other circumstances or configurations of other psychological/social forces have little or no effect on dislodging the perfectionist behavior patterns and the drive for approval. Upon the son's leaving home (at age 18, say), if he faced an identical set of psychological/social forces, he could conceivably exhibit the identical life history of behaviors, though such a requirement is not necessary. All that is required for a deterministic psychological description is that the forces of his past interactions with his father be strong enough to dominate all other psychological/social forces in determining his subsequent behaviors.

I propose capturing this property of a psychological description with the following "principle":

(PD) Principle of Determination: Some fixed set of (at least partially) identifiable crucial factors in a person's past governs their response to present events.

For therapeutic practice, as well as other purposes, the determining factors should be at least partially identifiable if psychologists are going to be in the "helping" or "clarifying" business. As formulated, PD leaves open the possibility that, facing the identical circumstances, a person would behave identically or merely very similarly. I take it that similarity of response is a strong enough requirement to sufficiently clarify the sense in which the determining set of past factors governs responses (i.e. limiting the range of responses down to one or some small set of similar responses). So each time the son's quest for approval is denied, he gets angry, but perhaps there is some slight variation to what he does with the anger.

## 4.3 Indeterministic Descriptions in Psychology

Though PD is suggestive, it lacks the kind of clarity we can achieve with UE in physical theories. Things get more vague in thinking about what kind of property characterizes an indeterministic description in psychology. Again, following the lead of our physics discussion, I want to explore what the negation of PD might mean. One obvious candidate to poke is the requirement that the set of past factors be fixed. Although we can only loosely define the boundaries of this set, it should be such that the collection of factors composing it are by far the strongest determinants of a person's behavior. Now if this set is constantly expanding and contracting, or if the members of this set are constantly changing, then there would be no consistent factors that are determining or shaping a person's behavior. That would call into question the idea of trying to pattern a principle of determination after UE, as I have tried to do with PD. Suppose the set of determining factors is changing. This does not imply that a person's behaviors are not governed by *some* set of factors from the past. So this suggests an even weaker "principle":

(PD*) Principle of Determination*: Some (possibly fixed) set of (at least partially) identifiable crucial factors in a person's past governs their response to present events.

What would the negation of PD* mean? I take it that the crucial element in the principle is that of governance. The sense of the word "govern" carries with it the idea of limiting the range of something (e.g. the governor on a carburetor limiting the speed of a car). I have already suggested the weaker notion of similar responses as appropriate for deterministic descriptions in psychology, but this leads to the question of how much similarity is required to count before a response would be judged "dissimilar". Not surprisingly, we find ourselves in the middle of all those thorny free will questions (see, e.g., the contributions by Dorato, Guignon, Kane, Martin and Sugarman, Richardson and Bishop in this volume). Obviously, if we make the range of possible responses wide enough, the sense in which any past factors are "governing" responses to present events becomes vacuous. Likewise it becomes difficult to understand how the responses come about.

On the other hand, if we take some of the elements in the set of determining past factors to be ones which we contributed to that set and which were not fixed by some prior factors earlier in history, then the sense of "govern" in (PD*) sounds less and less like determinism and more and more like incompatibilist free will. That kind of free will is thought to be inconsistent with determinism in the sense that we are the originators at an earlier point of some of the values guiding our actions in the present. In this case, our past history is consistent with, but underdetermines, this origination (Kane 1996 and in this volume). Of course there are problems with incompatibilist (and compatibilist) accounts of free will (e.g. Dorato, and Richardson and Bishop in this volume). Perhaps, then, it should be no surprise that some thoughtful critics within psychology (e.g. Slife and Williams 1995; Richardson, Guignon and Fowers 1999) argue that psychology needs to look beyond familiar debates concerning whether or not we are entirely subject to efficient causal influences stemming from the past and consider the possibility that notions of final and formal causation might make better sense of how meanings and values guide our activities and projects in the human realm.[13]

## 4.4 Taking Stock

At this point, it seems that we have reached an impasse similar to the one encountered in trying to frame a satisfactory description of physical indeterminism. Here we might appeal to our first person experience and observations of others to help adjudicate the ambiguity in an indeterministic psychological description. After all, our everyday experience is that of agents acting

[13]Some appeal to formal causation seems inescapable. For example, both PD and PD* assume that current circumstances form a context in which past influences can come to expression. The context of present circumstances is a formal cause influencing or constraining responses.

in the world producing effects and influencing outcomes, overcoming obstacles, voluntarily cooperating with others, and so forth. However, it appears that in psychology, as well as in physics, whether we interpret these experiences as being deterministic or indeterministic is not inscribed on the events themselves, but derives from our independently arrived at metaphysical commitments regarding determinism. Indeed, many of the free will debates turn on exactly this point. If we are convinced metaphysical determinists, then the negation of a principle like PD* will certainly not appear to yield an unambiguous statement of indeterminism in psychology. If we do not make any metaphysical presuppositions regarding determinism, then, in light of our first person experience and natural inclination to think of ourselves as having free will, the negation of principles like PD* will not appear suggestive of any deterministic construals.

Practically speaking, endorsing, denying, or remaining agnostic toward metaphysical determinism will almost certainly impact the practice of psychology more significantly than that of physics. This is not only because much of the methodology in psychology, in the minds of its practitioners, seems directly tied to a metaphysically assumed determinism, but also because the assumption of determinism directly impacts our conception of ourselves and others as persons (Rychlak 1979; Slife and Williams 1995; Richardson, Guignon and Fowers 1999; Gantt, and Slife in this volume). Hence the appeal of developing theories and explanations in psychology that give a central place to forms of final and formal causation. Such accounts clarify how human action is not so much propelled from behind, as it were, by efficient causes, but shaped and guided in different situations by shared goals and meanings – frequently renegotiated or reinterpreted in the business of living. Thinkers who take this path endeavor to develop a new ontology of the human life-world in which we can make better sense of the circumstances and influences that shape us and the ways we modify them in turn (see Guignon, Gantt, Richardson and Bishop, and Slife in this volume).[14]

[14] As Gunton (1993, pp. 51–61) argues, the development of the doctrine of divine freedom in the context of understanding creation – described briefly in footnote 11 – also plays a role in the sundering of the relationship between universals and particulars, as well as the sundering of relationships between particulars, that had a deleterious effect on our modern conception of human beings. This modern conception views humans as constituted primarily by abstract properties rather than constituted by the particularity of embodiment and relationship to other beings and the world. A life-world ontology would de-emphasize the former conception and emphasize the latter.

## 5 Discussion

To summarize, we have DD, UE and VD yielding precise mathematical properties for characterizing a deterministic description in physics, and we have DD*, UE*, VD* giving a conceptual characterization of indeterministic descriptions in physics. The property P* is an attempt to further clarify the properties of such an indeterministic description. In psychology, however, we have a rather vague PD and PD* as candidates for properties characterizing deterministic descriptions along with the quagmire of trying to understand what the properties of an indeterministic description might be like.

It may be possible to bring more mathematical precision to the properties of an indeterministic description in physics, and to further clarify some aspects of as well as alternative formulations to PD and PD*. However, I believe we can draw a general lesson from our explorations here: It appears unavoidable that our attitude toward metaphysical determinism plays an important role in understanding both the meaning and possibility of deterministic and indeterministic descriptions in both disciplines.

Do we have any evidence in favor of metaphysical determinism? Our first person experience of agency in the world certainly does not immediately suggest metaphysical determinism. Indeed, the assumption of metaphysical determinism requires us to go to considerable lengths – controversial at best as to their success – to reinterpret our notions of agency, individuality, creativity, praiseworthiness, blameworthiness and the like in order to make sense of them in a deterministic world (e.g. Honderich 1988, 1993; Pereboom 1995, 2001; Bishop 2002c). Phenomenological hermeneutics, and some kinds of final and formal causation are more in concert with our lived experience (see the contributions by Gantt, Guignon, Richardson and Bishop, and Slife in this volume).

One could argue that our best theories are deterministic and that this is evidence in support of metaphysical determinism. But it seems to me that it remains quite ambiguous as to whether theories such as quantum mechanics should be read in terms of ignorance or ontological construals of probability (cf. section 3). Furthermore, our best scientific descriptions are abstractions representing our best attempts to describe a complex world given our intellectual limitations and our purposes (Bishop 2002c). Our theoretical understanding, therefore, is always partial, limited and inexact even in our best theories and models. At best, then, these considerations point toward agnosticism about metaphysical determinism, so far as physics is concerned. Given the harsh clash between metaphysical determinism and our first person experience – which seems virtually impossible to eradicate from our understanding of ourselves in everyday life (Gantt, Guignon, Kane, and Richardson and Bishop in this volume) – I would lean in the direction of denying metaphysical determinism.

One might take this conclusion – that metaphysical determinism is not strongly supported by our best theories and first person experience – to mean we are forced into an instrumental attitude toward theories; namely, viewing theories as simply calculation tools that make no reference to real entities in the world (cf. van Fraassen 1980). After all, scientific realism – viewing the terms in our theories as referring in some subtle or complex ways to objects in the world – is often taken to go hand in glove with determinism. However, although I cannot really defend the point in this essay, I would suggest that agnosticism toward or even denial of metaphysical determinism is entirely consistent with either a realist or an instrumentalist attitude toward such theories.

The cost of doing away with metaphysical determinism in physics seems relatively minor, as indicated in section 3.4 above. In contrast, the effect of dropping this assumption in psychology leads to highly significant changes in our very conception of ourselves and others as persons, and in how we relate to and influence one another in important life enterprises. It also would lead to significant changes in social science methodology. The difficulty and uncomfortableness of such a change may be the price we have to pay for a better understanding of the human predicament. A number of the presentations in this volume speak to this vexing and important question.

## Appendix:
## A Comment on Differential Dynamics

Kellert takes DD to be both a necessary and sufficient condition for a model to be deterministic, if neither the mathematical representation of the system (including initial and boundary conditions) nor the differential equations make explicit reference to probabilities. This is the most fundamental layer of determinism in Kellert's analysis and is also the most obscure. That is because of an ambiguity in the meaning of determinism as differential dynamics. On the one hand, differential dynamics as determinism is the thesis that future states of a model or system evolve from past states in a mathematically definable way if the dynamical model makes no reference to probability (Kellert 1993, p. 57):

> ... a dynamical system has two parts: a representation of all possible states of the system and a set of equations that describes how the state

> of the system changes with time. When neither of these two parts involves chance explicitly, we have deterministic dynamical systems.

On this view (Kellert 1993, p. 56) "the way a system is at this moment determines, establishes, and specifies the way it will be at the next moment" by the equations describing the system. It is in this sense that unique evolution applies to models, systems and possibly, as some have thought, to our physical world.

On the other hand, differential dynamics also functions for Kellert (1993, p. 58) as a methodological tenet for scientific investigation:

> On the broadest scale, one could say that determinism as differential dynamics is just the tenet that we should keep looking for reasons for events in their pasts. The injunction is: use mathematical expressions (differential equations) to model the changes of physical systems; seek to understand or predict the future by relating it to the past with mathematical rules. Perhaps these rules will provide strictly unique implications and perhaps not, but keep trying to explain or predict until you cannot any more.

Methodologically, we seek to use "differential equations that make no explicit reference to chance – the equations must not include ... inherently stochastic elements" (Kellert 1993, p. 75). The import of this methodological point is to continue to use differential equations in our study of the world *without concern for whether UE holds.*

This methodological rule has its problems, however. First it is potentially misleading and uninformative. For example irreducible indeterminism in the initial conditions of chaotic systems due to quantum mechanics would be a case where the injunction will not produce models faithful to the dynamics of the physical system (Bishop and Kronz 1999). The methodological injunction would lead us astray in our attempt to model chaotic systems. The rule essentially tells us to use deterministic models (differential equations with no reference to chance) to capture the dynamics of chaotic systems when such systems may actually be indeterministic. Kellert's methodological construal of differential dynamics would leave us pursuing theories like $T$ described in section 3.3 above in our attempts to model and understand physical systems – a rather uninformative and potentially misleading half-way house between deterministic and indeterministic theories.

Second there is a question as to what the methodological rule means. We could construe it as a strong injunction in the sense that we are to use differential equations with no reference to indeterminism in our investigations of nature and push such models as far as we possibly can. Such a construal rules out any indeterministic collapse interpretation of quantum mechanics and, therefore, would undercut Kellert's main argument that UE can be completely separated from DD because macroscopic chaotic systems could amplify quantum effects (section 3.3 above). On the other hand we could construe the rule as a weak injunction in the sense that we start with non-probabilistic mathematical models as a first approximation and add in probabilistic elements as soon as it becomes apparent they are needed. On this weak construal, indeterministic collapse interpretations of quantum mechanics are allowed, but such an injunction adds nothing new to the physicist's tool bag.

That last point leads to an additional question concerning the binding force of the methodological injunction to use nonstochastic differential equations for the practice of science. For example the models and practices used in statistical mechanics plainly ignore the injunction because of the large number of parameters that compose the systems under study. Furthermore since the introduction of statistical methods in the 1800s, physics has made tremendous progress in terms of models that enable us to better understand a number of fundamental processes as well as to build countless practical devices. And even in cases where systems have a small number of relevant parameters but extremely complicated behavior – like chaotic systems – physicists do not always follow the rule. Instead they adopt whatever approaches are most likely to yield results. The force of differential dynamics as a methodological rule is weak at best in the face of the physicist's pragmatism.

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## References

Antoniou I. and Gustafson K. (1993): From probabilistic descriptions to deterministic dynamics. *Physica A* **197**, 153–166.

Atmanspacher H. (1994): Is the ontic/epistemic distinction sufficient to describe quantum systems exhaustively? In *Symposium on the Foundations of Modern Physics 1994*, ed. by K. Laurikainen, C. Montonen and K. Sunnarborg, Editions Frontières, Gif-sur-Yvette, pp. 15–32.

Atmanspacher H., Bishop R. and Amann A. (2001): Extrinsic and intrinsic irreversibility in probabilistic dynamical laws. In *Foundaitons of Probability and Physics*, ed. by A. Khrennikov, World Scientific, Singapore, pp. 50–70.

Bell J. (1987): *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge.

Bishop R. (1999): *Chaotic Dynamics, Indeterminacy and Free Will.* Ph.D. Dissertation. University of Texas at Austin.

Bishop R. (2002a): Chaos, indeterminism and free will. In *The Oxford Handbook on Free Will*, ed. by R. Kane, Oxford University Press, Oxford, pp. 111–124.

Bishop R. (2002b): Brussels-Austin nonequilibrium statistical mechanics: large Poincaré systems and rigged Hilbert space. *Studies in History and Philosophy of Modern Physics*, in press.

Bishop R. (2002c): Crisis in the behavioral sciences. Forthcoming.

Bishop R. and Kronz F. (1999): Is chaos indeterministic? In *Language, Quantum, Music: Selected Contributed Papers of the Tenth International Congress of Logic, Methodology & Philosophy of Science*, ed. by M. Dalla Chiara, R. Guintini and F. Laudisa, Kluwer, London, 129–141.

Bohm D. (1952a): A suggested interpretation of the quantum theory in terms of 'hidden variables' I . *Physical Review* **85**, 166–179.

Bohm D. (1952b): A suggested interpretation of the quantum theory in terms of 'hidden variables' II . *Physical Review* **85**, 180–193.

D'Espagnat B. (1994): *Veiled Reality: An Analysis of Present-Day Quantum Mechanical Concepts*, Addison-Wesley, Reading MA.

Earman J. (1986): *A Primer on Determinism*, Reidel, Dordrecht.

Fine A. (1971): Probability in quantum mechanics and other statistical theories. In *Problems in the Foundations of Physics*, ed. by M. Bunge, Springer, New York.

Gunton C. (1993): *The One, the Three and the Many: God, Creation and the Culture of Modernity*, Cambridge University Press, Cambridge.

Gustafson K. (1997): *Lectures on Computational Fluid Dynamics, Mathematical Physics, and Linear Algebra*, World Scientific, Singapore.

Gustafson K. and Goodrich R. (1980): A Banach-Lamperti theorem and similarity transformations in statistical mechanics. *Colloquium of the Mathematical Society of Janos Bolyai* **35**, 567–579.

Kane R. (1996): *The Significance of Free Will*, Oxford University Press, Oxford.

Hobbs J. (1991): Chaos and indeterminism. *Canadian Journal of Philosophy* **21**, 141–164.

Honderich T. (1988): *A Theory of Determinism: The Mind, Neuroscience and Life-Hopes*, Clarendon Press, Oxford.

Honderich T. (1993): *How Free Are You? The Determinism Problem*, Oxford University Press, Oxford.

Kellert S. (1993): *In the Wake of Chaos*, University of Chicago Press, Chicago.

Laplace P. (1814/1951): *A Philosophical Essay on Probabilities*, Dover, New York.

Lindberg D. (1992): *The Beginnings of Western Science: The European Scientific Tradition in Philosophical, Religious, and Institutional Context, 600 B.C. to A.D. 1450*, University of Chicago Press, Chicago.

Kochen S. and Specker E. (1967): The problem of hidden variables in quantum mechanics. *Journal of Mathematics and Mechanics* **17**, 59–87.

McMullin E. (1965): Medieval and modern science: continuity or discontinuity? *International Philosophical Quarterly* **5**, 103–129.

Pereboom D. (1995): Determinism al dente. *Noûs* **29**, 21–45.

Pereboom D. (2000): *Living Without Free Will*, Cambridge University Press, Cambridge.

Primas H. (1990): Mathematical and philosophical questions in the theory of open and macroscopic quantum systems. In *Sixty-Two Years of Uncertainty*, ed. by A. Miller, Plenum, New York, pp. 233–257.

Primas H. (1994): Endo- and exotheories of matter. In *Inside Versus Outside*, ed. by H. Atmanspacher and G. Dalenoort, Springer, Berlin, pp. 163–193.

Reichenbach H. (1956): *The Direction of Time*, University of California Press, Berkeley.

Richardson F., Fowers B. and Guignon C. (1999): *Re-envisioning Psychology: Moral Dimensions of Theory and Practice*, Jossey-Bass, San Francisco.

Rychlak J. (1979): *Discovering Free Will and Personal Responsibility*, Oxford University Press, Oxford.

Scheibe E. (1973): *The Logical Analysis of Quantum Mechanics*, Pergamon Press, Oxford.

Slife B.D. and Williams R.N. (1995): *What's Behind the Research? Discovering Hidden Assumptions in the Behavioral Sciences*, SAGE Publications, Thousand Oaks.

Stone M A. (1989): Chaos, prediction and Laplacean determinism. *American Philosophical Quarterly* **26**, 123–131.

Teller P. (1979): Quantum mechanics and the nature of continuous physical magnitudes. *Journal of Philosophy* **76**, 345–361.

Torretti R. (2000): 'Scientific realism' and scientific practice. In *The Reality of the Unobservable: Observability, Unobservability and Their Impact on the Issue of Scientific Realism*, ed. by E. Agazzi and M. Pauri, Kluwer, Dordrecht.

van Fraassen B. (1980): *The Scientific Image*, Oxford University Press, Oxford.

van Fraassen B. (1991): *Quantum Mechanics: An Empiricists View*, Clarendon Press, Oxford.

Xia Z. (1992): The existence of noncollision singularities in Newtonian systems. *Annals of Mathematics* **135**, 411–468.

# Perspectives on Scientific Determinism

**Gregor Nickel**

> After the decisive advance attained through Hume and Kant in the analysis of the causal problem, it is no longer possible to regard the causal relation as a simple connection between things, or to prove or disprove it in this sense. Ernst Cassirer

## 1 Introduction

The task of any philosophical consideration of (scientific) determinism should follow two paths: First, freedom – probably in a richer sense than mere origination (see Gantt and Guignon in this volume) – has to be asserted, since discussing the problem should make *sense*. Second, the "(unreasonable) effectiveness" of modern natural science should become understandable. And scientific determinism is certainly fundamental for natural science. There seems to be a contradiction between these two paths. A transcendental approach, i.e. not exploring the properties of "things" directly, but rather exploring the "nature" of a (scientific) *observation* of things, is *one* possible strategy – starting with Kant – to deal with this problem. This includes a critique of scientific or instumental reason (see Richardson and Bishop in this volume) and avoids the pitfalls of a naive compatibilism or incompatibilism with respect to the issue of free will.

In this article, I will try to be aware of Cassirer's warning quoted above (Cassirer 1956, p. 20), which he issued in his great essay *Determinism and Indeterminism in Modern Physics* – still one of the best works on this problem. I will focus on the second path and analyze the formal structure of determinism in modern natural science, with only a brief look at interpretational issues. In the next section, I will recall some elements of Cassirer's position as background. In the third section, I will propose a mathematical structure representing a framework for scientific determinism. Finally, I will have a critical look at the position of Emil du Bois-Reymond, representing the perspective of (classical) natural science.[1]

[1] With respect to a more detailed discussion of some philosophical perspectives (e.g. of

## 2 Ernst Cassirer

According to Cassirer, four different levels of scientific propositions can be distinguished:

1. Results of measurement[2] (this value here and now),
2. Scientific laws (e.g. the law of falling bodies),
3. Scientific principles (e.g. the principle of least action),
4. The causal principle (determinism).[3]

From each level to the next there is a *transcendental* transition, that is, e.g., a scientific law is not only a simple collection of measurement results. Rather, its formation requires (and provides) new insight not available at the lower level. Each higher level expresses a principle of unification with respect to the lower one.

The "causal principle" – according to Cassirer – says nothing about the physical objects, let alone the "world". It is only a principle for "the formation of empirical concepts" (Cassirer 1956, p. 19). Thus, it is only a methodological, not an ontological principle. However, it is constitutive for natural science, since it "guarantees" the unlimited possibility of scientific objectification.[4]

It is important to notice that Cassirer's description of determinism as a methodological principle, and its distinction from an ontological one, stands *outside* natural science. It is not to be confused with the distinction between "ontic" and "epistemic" descriptions as descriptions *within* science (see At-

Plato, Leibniz, Hume, and Kant), the reader is referred to Nickel (2000).

[2] Of course, there are no "brute facts" (measurement results) independent of theories or principles. Nevertheless, measurement results are here considered as "primitive elements" of physical theory. Their formation is itself a highly involved problem. Already at this point, an overly naive adoption of everyday language in the discussion of scientific theory appears problematic – science is formulated as a symbolic language from the very beginning.

[3] Though important for natural philosophy and scientific discussion, we will not focus on the difference between determinism (bidirectional in time) and causality (forward directed in time). For Cassirer, and also for the scope of this article, only their common structure is considered. So it should not be confusing when both terms will appear almost synonymously.

[4] This also cuts the connection between the causal principle and predictability, which is stressed by Cassirer (see also Atmanspacher and Primas in this volume).

manspacher in this volume).[5] All I have to say about scientific determinism is epistemic insofar as it does not refer to things as they are, when they are not observed (a mathematical formulation is a perspective as well as any other formulation). On the other hand, there is also an ontic aspect insofar as I will not deal with questions of determinability.

Following Cassirer's perspective, determinism will not be understood as a property of "things" or of the "world", but, rather, as an *a priori* principle for the scientific observer's *perspective* on things (compare Lombardi in this volume). Hence, the observer's *freedom* to choose a perspective or – closer to the language of science – to choose a theoretical framework and an experimental setting is fundamental (cf. Guignon and Primas in this volume). It is part of the freedom of the observer to choose a scientific perspective. Within this perspective, then, there are strict conditions which must not be violated. On Cassirer's view, one of these conditions is the principle of determinism.[6]

However, it is hardly possible to describe the formal principle of determinism used by Cassirer concretely and to discuss it *within* the framework of science. Therefore, I will follow a less formal procedure to formulate and discuss scientific determinism. During this discussion, I will repeatedly focus on the status of the observer.

## 3 A Mathematical Structure for Scientific Determinism

Following Kant, natural science has to be understood in terms of mathematical formalism and scientific experiment (Kant 1965, B XIIIf):

> Reason, holding in one hand its principles, according to which alone concordant appearances can be admitted as equivalent to laws, and in the other hand the experiment which it has devised in conformity with these principles, must approach nature in order to be taught by it. It must not, however, do so in the character of a pupil who listens to

[5] However, the ontic-epistemic distinction could be considered as a model for the tension between ontological and epistemological aspects of theories or things (or even more general: of perspective-dependence and -independence).

[6] It is important to note that scientific determinism regarded as a regulative principle has at least two different functions. First, it qualifies the correct scientific laws and concepts. Second, however, a completely deterministic representation of any system (taking into account all possible influences, thus leading to a deterministic representation of the world) is never accessible, so determinism expresses a "limit concept". Since an ultimately deterministic theory cannot be obtained in finite time, determinism as a regulative principle "guarantees" that the development of natural science will not terminate.

> everything that the teacher chooses to say, but of an appointed judge who compels the witnesses to answer questions which he has himself formulated.

In this section, I will concentrate on the principles of reason as they are codified in mathematical terms and propose a mathematical structure, sufficiently concrete to be instructive and sufficiently abstract to cover a large part of contemporary natural science. Thus, I will use the term (scientific) determimism only for describing a concept of natural science. What this has to do with determination in a philosophical sense remains open (compare Guignon, or Abe and Kobayashi, in this volume).

However, scientific determinism can be used as a framework for the discussion of concepts such as *reversible* and *irreversible* motion, *autonomous* and *nonautonomous* motion, and also for *stochastic* motion, both in scientific and in natural philosophy contexts. Implicit assumptions could become explicit, and the discussion could be clarified. In many *philosophical* discussions it is rather unclear what scientific determinism means, or – even worse – concepts such as nonautonomous motion and indeterministic motion are confused. On the other hand, for a *scientist* the framework of scientific determinism is usually much too clear, and it is worthwhile to realize that its basic assumptions are contingent and have to be justified. Needless to say, a representation of motion (i.e. change) in a mathematical framework (i.e. the unchanged/-able par excellence) is paradoxical enough.

Here and in the following, the term *motion* refers to any and all forms of temporal change. This is much more general than a mere change of location. As a mathematical framework for *scientific determinism*, the following conditions will be used.[7]

1. The object of inquiry is the *motion* of a *system* in *time*. All three concepts are represented by mathematical structures (sets).

2. *Time* is represented by the additive group of real numbers $\mathbb{R}$ (for reversible motion) or the additive semigroup of positive or negative real numbers $\mathbb{R}_+$ or $\mathbb{R}_-$ (for irreversible motion). We thus use the structure

[7] It should be emphasized again that these conditions are not self-evident. They represent the *historically* developed framework (still) used in a large spectrum of the sciences. Even in mathematics there are various concepts for modeling motion; we are concentrating here on the case of (reversible) motion with continuous time and global existence, and assume a particular time regularity. However, more complicated behavior can be discussed in a similar setting.

of a one-dimensional, homogeneous, ordered continuum $\mathcal{T}$ consisting of single points.[8]

3. The *system* under consideration is characterized by a set $\mathcal{Z}$ – the *state space*[9] – of distinct states $z \in \mathcal{Z}$, whose temporal sequence is to be studied. The set of all possible states of the system is thus fixed from the outset. For example, the state space of a planetary system is established by the positions and velocities (or momenta) of all planets, or the state space of an eco-system is established by the number of individuals belonging to each relevant species. For a stochastic time evolution, the state space is a space $L^1(\Omega)$ of probability densities.[10]

4. The *motion* of the system is represented by the temporal sequence of states, thus by a function $\mathcal{T} \ni t \mapsto z(t) \in \mathcal{Z}$, which maps each instant $t \in \mathcal{T}$ to one and only one state $z(t) \in \mathcal{Z}$.

These conditions describe the motion of a system as a mapping from time $\mathcal{T}$ into the state space $\mathcal{Z}$.[11] Motion, thus, inherits basic properties of the presupposed structure of time. Up to now, only one motion of the system has been described; no alternatives are taken into account. An observer *outside* the system can (at least theoretically) have a view of this motion as a whole by considering the complete function $z(\cdot)$. At a particular instant in time,

[8] This identification is not so innocent as it might appear. While many criticisms of it could be cited here, one from Hume will suffice (Hume 1974, p. 424): "The absurdity of these bold determinations of the abstract sciences seems to become, if possible, still more palpable with regard to time ... An infinite number of real parts of time, passing in succession, and exhausted one after the other, appears so evident a contradiction, that no man, one should think, whose judgement is not corrupted, instead of being improved, by the sciences, would ever be able to admit of it" (cf. Slife in this volume). It is remarkable that time in this setting is given by the same set $\mathcal{T}$ for all systems, while the state space depends on the system under consideration and the observer's preferences.

[9] In scientific applications, the state space has at least an additional (topological) structure defining for every state a neighborhood of similar states (see Primas this volume). While time in this setting is essentially the same for all systems, the state space depends on the particular system considered (or the observer's preferences).

[10] We thus consider a common framework for ontic or epistemic descriptions. For a formulation of determinism, this distinction is less important than for the interpretation of the state concept (compare Atmanspacher and Misra in this volume). This is to say, the evolution of a probability distribution following statistical laws can be given by the same mathematical structure (group or semigroup) as the evolution of a pure state. The "ontic" status of both is then considered to be the same.

[11] To avoid problems of notation, the discussion is now restricted to reversible motion, thus considering time as represented by the entire real axis $\mathbb{R}$.

the system itself has no option to "choose" any value of this function other than the prescribed value at this time.

In this situation the following (trivial) equation holds:

$$z((t-s)+(s-r)) = z(t-r) \tag{1}$$

for all $t, s, r \in \mathcal{T}$. The consequence of such an abstract decomposition of motion due to a presupposed atomic structure of time into individual steps – from $r$ to $s$ and from $s$ to $t$ – becomes clear only if a set of *all possible motions* is taken into account. This change of perspective is of major importance. The (human) observer definitely steps back from the stage and describes the motion from *outside* as if he could *repeat* the course of the world arbitrarily often at any given time.[12] This perspective, including the possibility of preparing suitable initial states, is thus a necessary condition for experimentation and, therefore, constitutive for modern natural science.

5. For every instant $t_0 \in \mathcal{T}$ and every initial state $z_0 \in \mathcal{Z}$ there exists one and only one (necessarily determined) motion $z_{t_0,z_0} : \mathcal{T} \to \mathcal{Z}$ which at time $t_0$ yields the state $z_0$ ($z_{t_0,z_0}(t_0) = z_0$).

Varying the initial time $t_0 \in \mathcal{T}$ and the final time $t_1 \in \mathcal{T}$ we obtain a family of mappings $\Phi_{t_1,t_0} : \mathcal{Z} \to \mathcal{Z}$ for the system under consideration. Every function $\Phi_{t_1,t_0}$ maps an arbitrary initial state $z_0 \in \mathcal{Z}$ to the state $z_{t_0,z_0}(t_1)$, reached at time $t_1$ by the unique motion starting at time $t_0$ in state $z_0$. Formally, we can write

$$\Phi_{t_1,t_0}(z_0) := z_{t_0,z_0}(t_1).$$

Every state $z_1 = \Phi_{t_1,t_0}(z_0)$ can itself be regarded as another initial state. The motion determined by the pair $(t_1, z_1)$ must coincide with the original motion, otherwise there were two different motions passing through $(t_1, z_1)$, contradicting condition 5. In terms of the mappings, the following equation holds:

$$\Phi_{t_2,t_1}(z_1) = \Phi_{t_2,t_1}(\Phi_{t_1,t_0}(z_0)) = \Phi_{t_2,t_0}(z_0).$$

Thus, we have the following fundamental equation

$$\Phi_{t,s} \circ \Phi_{s,r} = \Phi_{t,r} \tag{2}$$

[12] The importance of this step has been explicitly pointed out by Mach. Following his argumentation there is no cause and effect (or determined motion) in nature, since there is only *one* nature. It is *our* definition of similar (or equal) initial conditions yielding similar (or equal) effects (or motion), which enables us to speak of causality (Cassirer 1956, p. 195). Compare also Bishop, this volume.

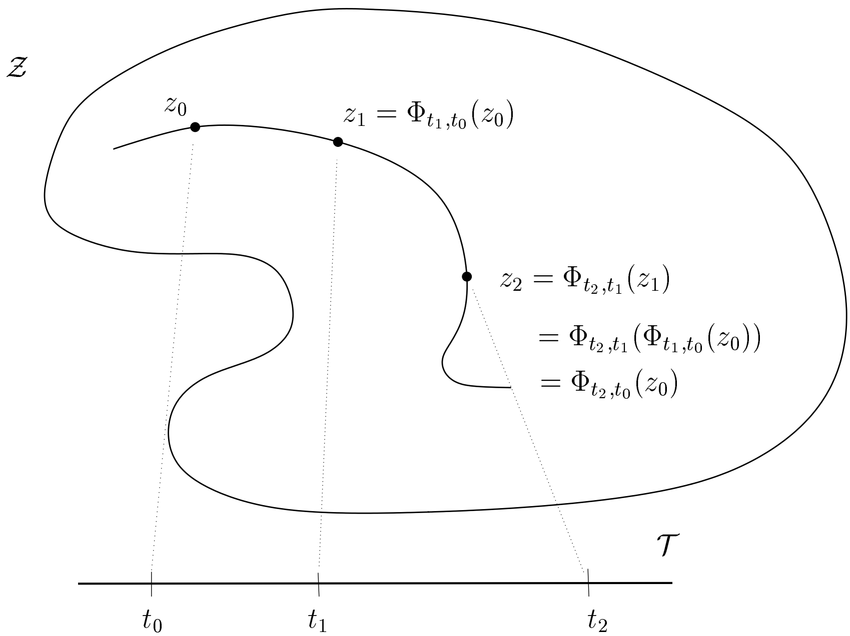


Figure 1: Evolution family

for all $t, s, r \in \mathcal{T}$. Moreover,

$$\Phi_{t,t} = Id \tag{3}$$

with the identical mapping $Id : z \mapsto z$ (compare Fig. 1).

This entire construction can be called *deterministic* on the basis of the following characteristics: the *a priori* choice of the state space, the representation of time by the set of real numbers $\mathbb{R}$, and, finally, the necessary existence of a unique motion for every possible initial state (see condition 5). In mathematical terms, a deterministic motion is given by a state space $\mathcal{Z}$, time $\mathcal{T}$, and a family of mappings (called an evolution family or propagator) $\Phi_{t,s} : \mathcal{Z} \to \mathcal{Z}$, satisfying equations (2) and (3).[13]

[13] The discussion of the implications of decomposing a motion into individual steps goes back at least to Aristotle. In his lecture on nature, he sharply distinguishes between an *actual* interruption of movement (that of a *"mobile"*, i.e. a moving object along a line) and its mere *possibility:* "... whereas any point between the extremities may be made to function dually in the sense explained [as beginning and as end], it does not actually function unless the mobile actually divides the line by stopping and beginning to move again. Else there were one movement, not two, for it is just this that erects the 'point between' into a beginning and an end ..." (Aristotle 1963, p. 373). In a case of continuous

In special situations, it can be assumed additionally that the system is not subject to external influences in the course of time. Such systems are called *autonomous*. The momentary state of their motion depends solely on the initial state $z_0$ and the time *difference* $t$ between initial and final time. The identity $\Phi_{t_1,t_o} = \Phi_{t_1+t,t_o+t}$ thus holds for any $t \in \mathcal{T}$, and a unique mapping

$$T_t : \mathcal{Z} \to \mathcal{Z}, \quad T_t := \Phi_{t,0} = \Phi_{t+t_o,t_o}$$

can be defined, which maps every initial state $z_0$ to the final state $z_1 = T_t(z_0)$, depending on the elapsed time difference $t$. The immediate consequences of equations (2) and (3) for the function $T$ are

$$T_s T_t = T_{t+s}, \quad T_0 = Id. \tag{4}$$

A family of mappings satisfying equation (4) is called either a one-parameter group (for $t \in \mathbb{R}$ in the reversible case) or a one-parameter semigroup (for $t \in \mathbb{R}_+$ or $t \in \mathbb{R}_-$ in the irreversible case).[14] The structure of a one-parameter (semi)group is, therefore, a mathematical model of autonomous, deterministic motion.[15]

motion, there is no justification for locating the object in the intermediate position (during a given period of time). "But if anyone should say that it [the mobile A, G.N.] has 'arrived' at every potential division in succession and 'departed' from it, he will have to assert that as it moved it was continually coming to a stand. For it cannot 'have arrived' at a point [B, G.N.] (which implies that it is there) and 'have departed' from it (which implies that it is not there) at the same point in time. So there are two points of time concerned, with a period of time between them; and consequently A will be at rest at B ..." (Aristotle 1963, p. 375). From this quite consistent perspective, the deduction of a relation as given in (2) certainly is problematic. And regarding the measurement problem of quantum mechanics, Aristotle's view seems quite modern.

[14] Irreversiblity implies a conceptual problem for an outside observer, since the *relative* time direction of the system and the observer must then be addressed, thus also his own motion. For a detailed discussion of the arrow of time see Primas in this volume.

[15] The semigroup equation (4) was explicitly used rather late in the literature of mathematical physics. Hille (1965, pp. 55–66), one of the founders of modern semigroup theory, writes: "Like Monsieur Jourdain in Le Bourgeois Gentilhomme, who found to his great surprise that he had spoken prose all his life, mathematicians are becoming aware of the fact that they have used semi-groups extensively even if not always consciously. ... The concept was formulated as recently as 1904, and it is such a primitive notion that one may well be in doubt of its value and possible implications." One of the first scientists who used semigroups to formulate a mathematical concept of determinism was Hadamard in his lectures on differential equations (Hadamard 1952, p. 53). With reference to Huygens' treatment of light diffusion, Hadamard discusses Huygens' "principle" in the form of a syllogism, whose major premise implicitly contains the semigroup law: "(major premise). The action of phenomena produced at the instant $t = 0$ on the state of matter at the

Whether the initial state determines the total motion, depends mainly on the choice of the state space. (For example, in the trivial, single-element state space $\mathcal{Z}_{Parmenides} := \{z_1\}$ there is only the (deterministic) trivial motion). However, the state space for a sensible description of a system should be established by those properties relevant for the observer, and, in addition, a given state at a specific time should determine any further motion. This corresponds to Cassirer's statement (Cassirer 1956, p. 6):

> The answer that an epistemology of science gives to the problem of causality never stands alone but always depends on a certain assumption as to the nature of the object in science. These two are intimately connected and mutually determine each other.

These (scientific, not objective!) requirements necessitate a careful balancing. The proper state space is precisely that which, on the one hand, contains all relevant properties, and, on the other hand, guarantees a deterministic motion (cf. Primas in this volume).[16] The history of physics shows numerous examples of how a state space was chosen that contained the relevant properties, but later was altered – usually enlarged – with the goal of achieving a deterministic motion, or semigroup property.

## 4 Emil du Bois-Reymond's Perspective on Nature

In 1872, the biologist, physiologist, and philosopher du Bois-Reymond reanimated the famous demon of Laplace (which correctly should be called Leibniz's demon), the notion of an intelligence overseeing the entire universe in all its details, in his address *On the Limits of Our Knowledge of Nature.* Years before the rise of quantum mechanics, the classical physical paradigm was particularly clearly expressed by du Bois-Reymond. It is worthwhile to consider his position since it reflects many problems discussed in the present debate in great clarity.

First, du Bois-Reymond formulated scientific determinism in a fairly clear cut way, although enabling its interpretation as an ontological and as a

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instant $t = t_0$ takes place by the mediation of every intermediate instant $t = t'$, i.e. (assuming $0 < t' < t_0$), in order to find out what takes place for $t = t_0$, we can deduce from the state at $t = 0$ the state at $t = t'$ and, from the latter, the required state at $t = t_0$." The premise is designated as a *"law of thought,"* or as a *"truism,"* which nevertheless has interesting consequences. For it corresponds (Hadamard 1952, p. 53) *"to the fact that the integration of partial differential equations defines certain groups of functional operations; and this for instance leads to quite remarkable identities ..."*

[16]For the case of hereditary mechanics the discussion about the proper state space and determinism is analyzed in Israel (1991).

methodological principle at the same time. Second, he discussed the problem of qualia and intentionality, emphasizing the tension between introspection and an outside scientific perspective. Third, he described the scientific perspective explicitely. Fourth, concerning the question of free will versus determinism, he tried to assert a consistent scientific world view, albeit with explicitly mentioned serious problems.

I do not agree with all his positions, but – in my opinion – du Bois-Reymond serves as a paradigm for the perspective of a natural scientist, both professionally and personally.

Within the framework of his scientific description of nature, he suggested a universal formula that would guarantee complete transparency (du Bois-Reymond 1912a, p. 443):[17]

> It is even conceivable that our scientific knowledge will reach a point which would allow the operation of the entire universe to be represented by One mathematical formula, by One immeasurable system of simultaneous differential equations, from which the position, the direction of motion, and the speed of every atom in the universe could be calculated at any time.

At the same time, however, du Bois-Reymond set up strict limits to knowledge. First, atomic matter, as presupposed by mechanics, is nothing more than a useful fiction; a "philosophical atom", conceived as existing beyond this pragmatic construction, is "on closer examination an absurdity" (du Bois-Reymond 1912a, p. 447). Second, not only consciousness, but even the simplest qualitative sensations, are irremediably out of reach for the natural scientist. Even complete and "astronomically exact" knowledge of all material systems, including the human brain, which is *in principle* attainable,[18]

[17] "... es läßt sich eine Stufe der Naturerkenntnis denken, auf welcher der ganze Weltvorgang durch Eine mathematische Formel vorgestellt würde, durch Ein unermeßliches System simultaner Differentialgleichungen, aus dem sich Ort, Bewegungsrichtung und Geschwindigkeit jedes Atoms im Weltall zu jeder Zeit ergäbe."

[18] It is remarkable that he does not mention the problem of the exact determinability of initial states and dynamical instabilities. This is in accordance with a long tradition at least from Leibniz on who already mentioned the "butterfly effect" in his small essay "On Destiny" (Leibniz 1951, pp. 571–572): "And often, such small things can cause very important changes. I used to say a fly can change the whole state, in case it should buzz around a great king's head while he is weighing important counsels of state ... . And even this effect of small things causes those who do not consider things correctly to imagine some things happen accidently and are not determined by destiny, for this distinction arises not in the facts but in our understanding." For Leibniz as for du Bois-Reymond the phenomenon of a sensitive dependence on initial conditions was no argument against a metaphysical determinism. One can ask why the opposite has become so popular nowadays.

so du Bois-Reymond, leaves the question of the nature of consciousness untouched, and natural scientists will always have to reply to this question with "ignorabimus". This claim is justified by the insurmountable gulf separating the quality-free descriptions of mechanics and the qualities of perception and intentionality (du Bois-Reymond 1912a, p. 457):[19]

> Astronomical knowledge of the brain ... reveals it to be nothing but matter in motion ... What conceivable connection is there between particular movements of particular atoms in my brain, on the one side, and, on the other, the facts which are primary, undefinable, indisputable for me: 'I feel pain, I feel pleasure; I taste something sweet, smell the scent of roses, hear the piping of the organ, see red' ... It is quite incomprehensible, and shall remain so for ever, that for a number of carbon, hydrogen, nitrogen, and oxygen atoms it is not a matter of complete indifference where they are and where they are going, where they were and where they went, where they will be and where they will be going ...

Du Bois-Reymond ascribes great importance to the "irreconcilable contradiction" between the "world-view established by mechanical physics" and the "freedom of the will". However, this contradiction is held to be logically subordinate to the problem of sensory qualities. Du Bois-Reymond's position in this matter is peculiarly vague. After having curtly brushed aside the various historical efforts[20] at grappling with the problem of free will as "most dark and self-inflicted aberrations", he formulates his "monistic view" as the result of a consequential application of the law of the conservation of energy (du Bois-Reymond 1912b, p. 82):[21]

[19] "Die astronomische Kenntnis des Gehirns, die höchste, die wir davon erlangen können, enthüllt uns darin nichts als bewegte Materie. Durch keine zu ersinnende Anordnung oder Bewegung materieller Teilchen aber läßt sich eine Brücke ins Reich des Bewußtseins schlagen. ... Die neben den materiellen Vorgängen im Gehirn einhergehenden geistigen Vorgänge entbehren also für unseren Verstand des zureichenden Grundes. Sie stehen außerhalb des Kausalgesetzes, und schon darum sind sie nicht zu verstehen, ... Es ist durchaus und für immer unbegreiflich, daß es einer Anzahl von Kohlenstoff-, Wassenstoff-, Stickstoff-, Sauerstoff-, usw. Atomen nicht sollte gleichgültig sein, wie sie liegen und sich bewegen, wie sie lagen und sich bewegten, wie sie liegen und sich bewegen werden."

[20] He refers, albeit negatively, to the efforts of contemporary French mathematicians to make room for free will within the framework of a theory of differential equations. According to these attempts, free will could be integrated into mechanical descriptions by taking into account bifurcations, which imply a breakdown of the uniqueness of the solutions of differential equations (see Israel 1991, and also Primas in this volume).

[21] "Die Erhaltung der Energie besagt, daß so wenig wie Materie, jemals Kraft entsteht oder vergeht. ... Die Hirnmolekeln können stets nur auf bestimmte Weise fallen, so sicher

> Conservation of energy means that force cannot be created or destroyed just as matter cannot ... The molecules of the brain can only fall in a particular way, as ineluctably as dice fall after leaving the tumbler ... Now if, as monism conceives it, our thoughts and inclinations, and this includes our acts of volition, are incomprehensible yet necessary side effects of the stirrings and fluctuations of our brain molecules, then it makes sense to say that there is no freedom of the will. For monism, the world is mechanistic, and in a mechanism there is no room for freedom of the will.

Yet eventually, du Bois-Reymond considerably qualifies his position in view of the exigencies of practical life. Even the "most resolute monist" could hardly maintain that each and every action is already predetermined by mechanical necessity. While it could be acceptable that unimportant actions are determined, this is hardly acceptable for meaningful (e.g. moral) decisions (cf. Guignon and Kane, this volume). With respect to a statistical determination, one could find acceptable that a statistically determined amount of letters have wrong addresses, but the assertion of a statistically determined amount of thieves in a society is scandalous.[22] For du Bois-Reymond, there is a fundamental and rationally undecidable alternative between strictly denying free will or asserting such free will at the expense of conceding an unsolvable "mystery". Thus, in du Bois-Reymond's account, the problem finds a new formulation rather than a solution.

wie Würfel, nachdem sie den Becher verließen. Wiche eine Molekel ohne zureichenden Grund aus ihrer Lage oder Bahn, so wäre das ein Wunder so groß als bräche der Jupiter aus seiner Ellipse und versetzte das Planetensystem in Aufruhr. Wenn nun, wie der Monismus es sich denkt, unsere Vorstellungen und Strebungen, also auch unsere Willensakte, zwar unbegreifliche, doch notwendige und eindeutige Begleiterscheinungen der Bewegungen und Umlagerungen unserer Hirnmolekeln sind, so leuchtet ein, daß es keine Willensfreiheit gibt; dem Monismus ist die Welt ein Mechanismus, und in einem Mechanismus ist kein Platz für Willensfreiheit."

[22] "... man gibt leicht zu, daß man nicht frei, sondern als Werkzeug verborgener Ursachen handelt, so lange die Handlung gleichgültig ist. Ob Caesar in Gedanken die rechte oder linke Caliga zuerst anlegt, bleibt sich gleich, ... ob er aber den Rubicon überschreitet oder nicht, davon hängt der Lauf der Weltgeschichte ab. ... Wenn Herr Stephan uns berichtet, daß auf hunderttausend Briefe Jahr aus Jahr ein so und so viel entfallen, welche ohne Adresse in den Kasten geworfen werden, denken wir uns nichts besonderes dabei. Aber daß nach Quetelet unter hunderttausend Einwohnern einer Stadt Jahr aus Jahr ein so und so viel Diebe, Mörder und Brandstifter sind, das empört unser sittliches Gefühl ..." (du Bois-Reymond 1912b, p. 86).

## 5 A Perspective on du Bois-Reymond's Position

Let me finally add some remarks on du Bois-Reymond's position, the perspective of a typical scientific observer. For him, objects are given by mechanical atoms within a state space $\mathbb{R}^{6N}$; the connection between atomism and his natural philosophy is remarkably close. Natural science and the mechanics of atoms are almost identical.[23] However, there is an ambiguity in du Bois-Reymond's atomism: On the one hand, the real world has to be analyzed in terms of the motion of atoms, but, on the other hand, he thinks of the atom merely as a "useful fiction". A similar ambiguity holds for his considerations on determinism and free will.

The origin of these ambiguities can be found in his perspective of an outside observer, detached from the phenomena (cf. Gantt and Guignon, this volume). A scientific observer looks at a system (including his own brain) and considers every detail without being involved. Du Bois-Reymond calls this an "Archimedean perspective" and describes it often with great pathos in his writings.[24] Although he admits the one-sidedness of the scientific perspective,[25] he defends it as unique and objective in contrast to other per-

[23] "Kant's Behauptung in der Vorrede zu den Metaphysischen Anfangsgründen der Naturwissenschaft, 'daß in jeder besonderen Naturlehre nur so viel eigentliche Wissenschaft angetroffen werden könne, als darin Mathematik anzutreffen sei' – ist also vielmehr noch dahin zu verschärfen, daß für Mathematik Mechanik der Atome zu setzen ist" (du Bois-Reymond 1912a, p. 442). In quantum mechancis, and also in continuum mechanics, the concept of objects is quite different, but it remains to be clarified whether this has substantial implications for the problem of determinism.

[24] "Aber man denke sich einen Augenblick den unendlichen Raum, und im unendlichen Raume verteilt Nebel chaotischer Materie, Sternhaufen, Sonnensysteme; man denke sich, als verschwindenden Punkt in dieser Unendlichkeit, unsere Sonne in unbekannte Himmelsräume stürzend, um sie her die Planeten ... Wir wollen diese der anthropozentrischen entgegengesetzte Art, die Vorgänge auf der Erde zu betrachten, die archimedische Perspektive nennen, weil wir dabei geistig einen Standpunkt außerhalb der Erde wählen ... Wie armselig und unbedeutend erscheinen so gesehen die irdischen Dinge! ... Wie gänzlich wahnsinnig ihr Beginnen, wenn eine Versammlung der ernstesten, gelehrtesten, tiefstdenkenden Männer ihrer Zeit über Wesensgleichheit oder Wesensähnlichkeit von Vater und Sohn zu Rate sitzen!" (du Bois-Reymond 1912a, p. 595f) This perspective includes an "introspection from the outside": "Es wäre grenzenlos interessant, wenn wir so mit geistigem Auge in uns hineinblickend die zu einem Rechenexempel gehörige Hirnmechanik sich abspielen sähen ..." (du Bois-Reymond 1912a, p. 457).

[25] "In diesem Sinne schein uns heute erlaubt, ja nützlich, das Weltproblem von verschiedenen Standpunkten aus anzugreifen, und demgemäß eine mechanische Welttheorie aufzustellen und in sich zu begründen, unbekümmert zunächst darum, wie Ethik, Rechtslehre und hergebrachte menschliche Vorstellungen damit fertig werden" (du Bois-Reymond 1912a, p. 531).

spectives. Any "introspection" is explicitly rejected as part of the scientific method (du Bois-Reymond 1912b, p. 85f).[26]

On the other hand, du Bois-Reymond does not disregard the dilemma of inner and outer perspectives, which is normally avoided by the "sleepwalking one-sided scientist or poet".[27] Perhaps this dilemma could be more properly appreciated if the scientific world view were understood as one particular perspective among many (cf. Guignon, this volume). In Kant's words (Kant 1965, A 125f):

> ... the order and regularity in the appearances, which we entitle nature, we ourselves introduce. We could never find them in appearances, had not we ourselves, or the nature of our mind, originally set them there. For this unity of nature has to be a necessary one, that is, has to be an a priori certain unity of the connection of appearances; and such synthetic unity could not be established a priori if there were not subjective grounds of such unity contained a priori in the original cognitive powers of our mind, and if these subjective conditions, inasmuch as they are the grounds of the possibility of knowing any object whatsoever in experience, were not at the same time objectively valid.

Kant (and later Cassirer) provide examples of a balanced conception, asserting freedom (as a fundament), but at the same time appreciating the plausibility and effectiveness of science and scientific determinism. However, the twofold meaning of the word "nature" in the preceding quote renews the problem. Kant's transcendental position was misinterpreted psychologically, and, more seriously, his dualistic balance – with a courteous distance to a possible unifying ground – was given up in German idealism (monism of spirit, where natural philosophy and natural science are almost disjoint)

[26] Every attempt to analyze the *subject* of experience and reason immediately collapses to an "objective" picture: "Wenn wir auf den Fluß unserer Gedanken achten, bemerken wir bald, wie unabhängig von unserem Wollen Einfälle kommen, Bilder aufleuchten und verlöschen. Sollten unsere vermeintlichen Willensakte in der Tat viel willkürlicher sein?"

[27] "Wer gleichsam schlafwandelnd durch das Leben geht, ... wer als Historiker, Jurist, Poet in einseitiger Beschaulichkeit mehr mit menschlichen Leidenschaften und Satzungen, oder wer naturforschend und -beherrschend eben so beschränkten Blickes nur mit Naturkräften und Gesetzen verkehrt: der vergißt jenes Dilemma, auf dessen Hörner gespießt unser Verstand gleich der Beute des Neuntöters schmachtet; wie wir die Doppelbilder vergessen, welche Schwindel erregend uns sonst überall verfolgen würden" (du Bois-Reymond 1912b, p. 87). In this context, Buber's diagnosis in *Ich und Du* (Buber 1983) is of interest. Mental impairments produced by a worldview based on doom ("Verhängnis") and arbitrariness ("Willkür"), as more or less unrelated aspects of determinism and chance, are contrasted with fate ("Schicksal") and freedom ("Freiheit"), being related in a meaningful way.

or materialism (monism of matter, where at most natural science is taken seriously).

The structure of Kant's argument could be revived by turning away from the *a priori* emphasis on both Euclidean time and space and Aristotelian logic. This would lead to a picture in which Kant's categories (including causality) are valid only in some local sense. A "transcendental pragmatic" or "transcendental phenomenological" account might try to understand the human observer (at least) as reasoning *and* acting (as Blondel (1893) pointed out). The determining force of logical reasoning is then only *one* important aspect/possibility for the constitution of human existence.[28]

Certainly, such approaches cannot immediately provide *definite* solutions (since *freedom* is crucial). But they could lead to a re-action of thinking to the contingent history of science and philosophy and to a renewal of the Kantian balance. Maybe they could even lead to a viewpoint integrating the position of du Bois-Reymond (1912b, p. 87):[29]

> The writings of the metaphysicians offer a long series of attempts at reconciling freedom of the will and moral law with a mechanical order of the universe. If anyone, Kant for example, had achieved this squaring of the circle, then this series would reach its end. Only inconquerable problems are in the habit of being so immortal.

## References

Aristotle (1963): *Physics*, transl. by P.H. Wicksteed and F.M. Cornford, William Heinemann, Cambridge.

Blondel M. (1893): *L'Action. Essai d'une critique de la vie et d'une science de la pratique*, Alcan, Paris. See also his "L'illusion idèaliste", *Revue de mètaphysique et de morale* **6** (1898), 726–745, and his "La point de départ de la recherche philosophique", *Annales de philosophie chrétienne* **151** (1906), 337–360.

Buber M. (1983): *Ich und Du*, Lambert Schneider, Heidelberg.

[28]See also the arguments presented by Guignon in this volume. Perhaps, a transcendental version of Peirce's picture, as presented by Kronz and McLaughlin in this volume, might also be relevant.

[29]"Die Schriften der Metaphysiker bieten eine lange Reihe von Versuchen, Willensfreiheit und Sittengesetz mit mechanischer Weltordnung zu versöhnen. Wäre einem, etwa Kant, diese Quadratur wirklich gelungen, so hätte wohl die Reihe ein Ende. So unsterblich pflegen nur unbesiegbare Probleme zu sein."

Cassirer E. (1956): *Determinism and Indeterminism in Modern Physics*, Yale University Press, New Haven.

du Bois-Reymond E. (1912a): *Reden in zwei Bänden, Band 1*, Veit, Leipzig.

du Bois-Reymond E. (1912b): *Reden in zwei Bänden, Band 2*, Veit, Leipzig.

Hadamard J. (1952): *Lectures on Cauchy's Problem in Linear Partial Differential Equations*, Dover, New York.

Hille E. (1965): What is a semi–group? In *Studies in Real and Complex Analysis*, ed. by J. Hirschmann, *MAA Stud. Math.* **3**, 55–66.

Hume D. (1974): An enquiry concerning human understanding. In *The Empirists*, Anchor Book, Garden City, New York.

Israel G. (1991): Il determinismo e la teoria delle equazioni differenziali ordinarie. *Physis* **28**, 305–358.

Kant I. (1965): *Critique of Pure Reason*, transl. by N.K. Smith, St. Martin's Press, New York.

Leibniz G.W. (1951): *Selections*, ed. by P.P. Wiener, Charles Scribner's Sons, New York.

Nickel G. (2000): Determinism: Scenes from the interplay between metaphysics and mathematics. In *One-Parameter Semigroups for Linear Evolution Equations*, ed. by K. Engel and R. Nagel, Springer, Berlin, pp. 531–553.

# Determinism Is Ontic, Determinability Is Epistemic

**Harald Atmanspacher**

**Abstract**

Philosophical discourse traditionally distinguishes between ontology and epistemology and generally enforces this distinction by keeping the two subject areas separated. However, the relationship between the two areas is of central importance to physics and philosophy of physics. For instance, many measurement-related problems force us to consider *both* our knowledge of the states and observables of a system (epistemic perspective) *and* its states and observables independent of such knowledge (ontic perspective). This applies to quantum systems in particular.

This contribution presents an example showing the importance of distinguishing between ontic and epistemic levels of description even for classical systems. Corresponding conceptions of ontic and epistemic states and their evolution are introduced and discussed with respect to aspects of stability and information flow. These aspects show why the ontic/epistemic distinction is particularly important for systems exhibiting deterministic chaos. Moreover, this distinction provides some understanding of the relationships between determinism, causation, predictability, randomness, and stochasticity.

## 1 Introduction

Can nature be observed and described as it is in itself independent of those who observe and describe – that is to say, nature as it is "when nobody looks"? This question has been debated throughout the history of philosophy with no clearly decided answer one way or the other. Each perspective has strengths and weaknesses, and each epoch has had its critics and proponents with repect to these perspectives. In contemporary terminology, the two perspectives can be distinguished as topics of ontology and epistemology. Ontological questions refer to the structure and behavior of a system as such, whereas epistemological questions refer to the knowledge of information gathering and using systems, such as human beings.