ANR-DFG 2008

Institut d'Histoire et de Philosophie
Sciences et des Techniques
(CNRS/Paris I/ENS)
*
Fachbereich Philosophie
Universität Konstanz

Causality and Probability

CAUSAPROBA

1. General Information

1.1 Names and Addresses:

Directors of the Project:

Prof. Dr. Jacques Dubucs, Senior Scientist (CNRS)

Institut d'Histoire et de Philosophie
des Sciences et des Techiques
13 rue du Four
75006 Paris
France
Phone: +33 1 43 54 60 36
Fax: +33 1 43 25 29 48
jacques.dubucs@univ-paris1.fr

Prof. Dr. Wolfgang Spohn

Fachbereich Philosophie
Universität Konstanz
Postfach D21
78464 Konstanz
Deutschland
Phone: +49 7531 88 2503
Fax: +49 7531 88 4121
wolfgang.spohn@uni-konstanz.de

Further Collaborators:

Dr. Anouk Barberousse, Junior Scientist (CNRS)
Same address as above
barberou@heraclite.ens.fr

Philippe Huneman, Junior Scientist (CNRS)
Same address as above
huneman@wanadoo.fr

Matteo Morganti, Post-Doctorate, IHPST
Same adresse as above
M.Morganti@lse.ac.uk

Mikaël Cozic, Post-Doctorate, IHPST
Same adresse as above
Mikael.cozic@ens.fr

Brian Hill, Affiliated Professor
Groupe HEC
1, rue de la Libération
78351 Jouy en Josas cedex
brian@brian-hill.org

Max Kistler, Professor
Département de Philosophie
Université Pierre Mendès-France
Bâtiment ARSH
1281, avenue Centrale,
38400 Saint-Martin d'Hères
Maximilian.Kistler@upmf-grenoble.fr

Isabelle Drouet, Post-Doc, IHPST
i.drouet@9online.fr

Cyrille Imbert, PhD Student, IHPST
Cyrille.Imbert@normalesup.org

Eric Raidl, PhD Student
IHPST and Konstanz
raidl@clipper.ens.fr

Dr. Franz Huber
Director of the Emmy-Noether
Research Group "Formal Epistemology"
at the University of Konstanz
franz.huber@uni-konstanz.de

(and his collaborators)

Alexander Reutlinger, Ph.D. Student
same address as above
hagbart_5@web.de

Stefa Hohenadel, Ph.D. student
same address as above
Stefan.Hohenadel@uni-konstanz.de

Associate Advisors and Collaborators:

Prof. Paul Humphreys
Corcoran Department of Philosophy
University of Virginia
120 Cocke Hall, P.O. Box 400780
Charlottesville, VA 22904
USA

Prof. James Woodward
Division of Humanities and Social Sciences
California Institute of Technology
Pasadena, CA 91125
USA

1.2 Title of the Project : Causation and Probability

Keyword: Causation, Probability

Acronym: CAUSAPROBA

1.3 Area of Specialization:

Domain: Philosophy, Specialization: Philosophy of Science

1.4 Period of Application: April. 1, 2009 – March 31, 2012

1.5 Summary:

Causation, in particular in its connection to probability, has emerged as one of the most active fields in philosophy of science and its neighboring fields. Still, the current state of research is incomplete; central issues are starting being tackled only in the recent years or are even not really in the focus. The joint project wants to inquire four such issues: When precisely does a specific event or fact *actually* cause another event or fact? (As opposed to: what are causal laws?) How precisely are "this-worldly" mechanistic conceptions of causation related to "other-worldly" counterfactual conceptions? How can we have causation on different (micro and macro) levels and how then do the levels relate? And in which sense are causal relations features of objective reality? Whereas the first three subprojects engage in various details of the foundations of causal theorizing, the fourth subproject deepens the philosophical background of the current discussions. All subprojects have their own topic; but they are interrelated, and they will immensely profit from mutual cooperation. Together they will considerably promote the current state of research. For all subprojects, the role of probability is of vital importance; so, probabilistic methodology will be a further uniting component of the joint project. The IHPST and the Philosophy Department of the University of Konstanz are leading institutions for philosophy of science in their countries and have a long-standing cooperation. Thus they create optimal presuppositions for a successful implementation of the joint project.

2. State of Research, Own Preparatory Work

2.0 General Introduction

Why Causation?

Causation is a very old topic. It started in Greek philosophy with Aristotle's famous four notions of cause. It had a long history in Arabic and medieval philosophy under the label of occasionalism. It started its modern career with Hume's most influential criticism of causal necessity. It figured centrally in Kant's philosophy. It fell in disgrace in the late 19th century as bad metaphysics, as "a relic of a bygone age" in Russell's famous dictum. It reappeared in the 50s under the label "scientific explanation" and then slowly under its own label. Since around 1970 it has most forcefully returned on the philosophical agenda; a survey over recent volumes of philosophy journals immediately shows that causation is one of the most active fields in philosophy of science and its interdisciplinary neighbors. Since, the world has seen more literature on the topic than before. Still, despite the most vigorous and extended efforts, the current state of research is often incomplete, not only in the trivial sense that the possible ramifications are little inquired at the far end, but in the sense that apparently central issues have been seriously tackled only in the last eight years or are still not really in the focus of the discussion. In this joint project we want to take up four distinct, but interconnected issues that should be fruitfully advanced by our cooperative efforts.

Why Probability?

The return of the topic has two main reasons. The minor one was that with Lewis (1973) counterfactual analyses of causation, that were badly needed, have become feasible; this was a crucial progress. The major reason was that, after the quantum physical shock that seemed to deny causation on the basic microphysical level altogether, theories of probabilistic causation emerged around 1970. They were much more sophisticated than the corresponding efforts on the deterministic side, and they had a much closer contact to the natural and social sciences. So, they soon took the lead. With the theory of causal graphs and Bayesian nets (Pearl 1988, 2000, Spirtes et al. 1993, foreshadowed in Spohn 1980), a most powerful and widely applicable theory has emerged that today belongs to the standard foundations of the topic. So, whatever the specific topics inquired, the connection between causation and probability plays a basic and important role.

Why four topics, and why these four?

We have selected four topics: A: actual causation, B: counterfactual vs. mechanistic accounts of causality, C: multi-level causation, and D: the objective reality of causality. The obvious reason is that we feel particularly competent for these topics and can develop a fruitful cooperation on them. But there is more to it.

First, each of the four topics would certainly be suitable for a separate project; each could be interesting by its own. But, of course, even though well-defined by themselves, the topics overlap. It is important to pursue the repercussions of the results of one subproject within another and to critically check the overall coherence. There is no doubt that the synergies between the parts will be consider-

able (as the application will explain in detail). None of the subprojects could be easily missed. Even within our foundational orientation one could imagine much larger projects. However, four projects strike a good balance between the desirable synergies and our resources and capacities.

Why then these four topics? There would be a host of more applied projects. However, even though the proximity to the sciences is natural and important to us, we are philosophers of science interested in foundational topics, and this is what we have focused on in our selection. We have excluded a most important foundational issue: causation in the quantum world, because it is well separable from many other discussions of causation and because it requires specialized philosophers of physics rather than general philosophers of science like us. We were less interested in developing individual accounts of causation, although none of them can be called complete in any way. Our focus is rather on comparative studies. The most fascinating point of the present discussion is the competition and the complementarity of the various approaches which is unresolved and little understood. Only comparative studies can really advance this situation. Therefore we have identified four hot spots of comparative interest in the present discussion, as will be explained in more detail in the individual subprojects.

All four subprojects are closely tied to probability. The study of actual causation must make sense also in the probabilistic realm and requires an appropriate interpretation of probability, sensitive to causal facts. Mechanistic accounts of causality, that emerged as rivals of the probability increase theory of causation, raise the question of local “propensity-carrying” processes. As regards multi-level causation, one central problem is the scope and the limits of the statistical tools to get prediction at the macro-level from the knowledge of the interactions at the micro-level. And objectivity issues are firmly bound up with the interpretation of probability. So, probabilistic methods will play an important role throughout.

Why IHPST and the University of Konstanz?

Both sides are very well suited for the joint project, individually as well as jointly.

First, the two principal investigators are engaged in the relevant topics for decades and internationally acknowledged for their work (see the appended CVs). IHPST is currently considered to be the leading French lab in philosophy of science and the Department of Philosophy at the University of Konstanz is renowned for its strength in philosophy of science.

Second, although IHPST and the Philosophy Department at Konstanz never developed a joint program until now, they share the same scientific objectives and values, resting on a long-standing, though discontinuous cooperation. It started with an invitation of Spohn to the conference “Philosophy of Probability” in Paris 1991 organized by Dubucs (see Dubucs (1993a). Gabriella Crocco, a PhD student of Dubucs, (currently Associate Professor in Aix en Provence), had a fruitful 1-year research stay in Konstanz close to Fuhrmann and Spohn. Contact continued due to international applications at the ESF (see below). Last year Dubucs and Spohn started the joint supervision of the PhD thesis of Raidl, Fellow of the International Selection of the École Normale Supérieure in Paris, and Spohn was a member of the dissertation committee Isabelle Drouet.

The two centers bring in their individual complementary strengths into the joint project. Konstanz is an internationally acknowledged place for work on causality and formal epistemology, while IHPST’s main force-lines are logic and philosophy of science. Spohn has made original and acknowledged contributions to the topics A (actual causation) and D (the objective reality of causation), while Dubucs and his collaborators have a big record concerning topics B (counterfactual vs. mechanistic accounts

of causality) and C (multi-level causation). For details see section 2.2. These strengths will be combined in a close cooperation. For the detailed cooperative plans see section 3.2.

The suitability of the two places is also supported by brief description of the personnel and the scientific environment. As far as IHPST is concerned:

– IHPST has an abundant staff, by far the largest one in France, of motivated young philosophers, each of them equipped with a solid background in a particular science, in agreement with the IHPST requirement of "direct acquaintance" with a particular science (Barberousse and Imbert have an academic cursus in physics, Morganti in quantum mechanics, Huneman in mathematics and biology, Kistler in engineering, Drouet and Raidl in mathematical logic). Most of those people work together for a couple of years on two particular aspects (computational emergence, functional explanations) of the multi-level causality problem. Huneman and Kistler have already started to work on the mechanism/counterfactualism alternative.
– The association of Prof. Paul Humphreys to IHPST is a great opportunity for the project. He is an internationally acknowledged expert in the field, has written a book (1989) on probabilistic causation and he closely collaborated with Wesley Salmon while he was developing his own theory in terms of mechanisms. He has collaborated with IHPST people on various topics related to the project and also with Spohn on the Festschrift for Patrick Suppes. He has promised to participate at the project as well, to the profit of the whole group.

As far as the University of Konstanz is concerned:

– Spohn continuously supervises master and doctoral theses related to the topics of the project (Fahrbach 2002 (PhD), Dudau 2003 (PhD), Rosenthal 2004 (PhD), Bergt 2004 (MA), Haas 2005 (PhD), Kleyer 2006 (MA), Bigliardi 2008 (PhD) and presently dissertations by Alexander Reutlinger and Stefan Hohenadel), besides other topics as well. Thus, there always existed a larger (changing) internal working group.
– In January 2008 the Emmy-Noether research group "Formal Epistemology" directed by Dr. Franz Huber started its work, continuing for five years. There will be natural close contacts between our project and that group.
– In October 2007 the University of Konstanz became one of nine "elite" universities in Germany. This tremendously increases the research facilities at the University. One of the funding lines from which the present project can immediately profit is the so-called Zukunftskolleg where senior fellows are invited and junior fellows can apply for cooperation. Prof. Jim Woodward from CalTech, also an internationally renowned expert on the field has a standing invitation to the Kolleg and he has promised to cooperate with our project; it is presently not yet clear when the invitation will realize.

Hence, at both sides the projects will be embedded in a larger fruitful environment. There is, however, even a broader European and international context:

– In November 2007 the European Philosophy of Science Association (EPSA) was founded at a constitutional congress in Madrid. Both the French and German side helped a lot in the background.
– In connection with EPSA, the European Journal for the Philosophy of Science (EJPS) is about to be launched. Huneman from IHPST is actively engaged in the process, Spohn will probably act as a senior advisor.
– A Research Networking Program Proposal, PSE ("Philosophy of Science in a European perspective) has just been accepted by the European Science Foundation. It is directed by a consortium consisting of Prof. Galavotti (Bologna), Prof. Redei (Budapest/London), and Prof. Wolters (Kon-

stanz). There is no doubt that this European networking project will profit from an actual research program like the present Paris/Konstanz project.

– IHPST as well the Philosophy Department in Konstanz have continuous collaborations with the London School of Economics and with the new Department of Philosophy of Science of Tilburg (Prof. Hartmann). Moreover, both have a regular and intense partnership with the world-wide leading Department of History and Philosophy of Science of Pittsburgh University and with the Carnegie-Mellon University in Pittsburgh.

This is a most valuable context in which we are well embedded. On the one hand, this context makes it easy to disseminate the results of our joint project. On the other hand, the items show that the activities promoting and integrating philosophy of science on a European level have acquired strength only recently. Besides the excellent topical and personal fitting, the intention to distinctly contribute to this European integration is a driving force behind our joint ANR-DFG application.

2.1. State of Research

A. Actual Causation:

For a surprisingly long time, research focused on the nature of causal laws in the deterministic case or on causal dependence among variables in the probabilistic case. The apparently basic notion of actual singular causation, i.e. “the event or fact *A* is actually a (partial) cause of the event or fact *B*”, has found far less interest, perhaps because the large and in a way leading literature on probabilistic causation rather focused on the general level of statistical and causal laws. This has considerably changed only in the recent years:

With a little streamlining that is unavoidable in such a brief summary, one might say that the counterfactual analysis of causation of Lewis (1973) is the only of the elder approaches still considered that expressly tackled the basic notion. Its theoretical state is improvable, though. The neural diagrams, for instance, on which it heavily relied as a visual aid never were the objective of graph theoretical theorizing. And that there may be many difficult cases pertaining to the singular, but not to the general level (e.g., concerning transitivity, various form of overdetermination, preemption, and prevention) has become fully clear only with the recent upturn of the counterfactual analysis (cf. Collins et al. 2004 that summarizes about 7 years of research).

However, serious rivals came up in this decade. Pearl (2000) was the first within the large and successful literature on Bayesian nets and their causal interpretation who tried to explain actual singular causation within this framework. This idea is further developed in detail by Halpern and Pearl (2005). A variant of that structural model approach is proposed and extensively related to the counterfactual approach by Woodward (2003, chs. 2+3). Spohn (2006) reinforces his old treatment of the topic from the ranking-theoretic point of view that is closely related to both, the Bayesian net and the counterfactual approach.

It may suffice to point to these major approaches. The literature on them is quite recent, and only through this literature the topic of actual causation has again moved into the focus of discussion. The secondary literature has not yet had so much time to evolve. When one looks more closely at these approaches, surprising divergences become apparent. Their philosophical motivations or foundations are quite different, their theoretical credentials diverge, and even though they agree on major examples and applications, they disagree on many other examples and arrive at diverging causal judgments about them.

This is a situation that urgently calls for a pervasive and systematic comparison that does not yet exist, that seems clearly feasible given the remarkably specific elaboration of the competing proposals, and that is the task we want to tackle in this part of our project.

B. Counterfactual vs mechanistic accounts of causality

Counterfactual accounts of causation appeal to possible worlds in order to explicate the causal relations in the actual world. Although this provides us with powerful logical analyses of causal statements, many people have been reluctant to allude to other worlds in the analysis of causation, since scientific explanations are clearly concerned with what happens in this world and thus purport to refer only to actual items. Salmon (1984) proposed his process account of causation that contrasts with counterfactual accounts by trying to define causation only in terms of this-worldly matters of fact, i.e. conserved quantities (see also Dowe 2000, Ellis 2002). Since probabilistic accounts of causation are closely related with counterfactual accounts (e.g. via the concept of statistical relevance first forged by Salmon – see also Hitchcock 2001), the process account represents a radically novel way of understanding causation.

Recently, this family of this-worldly theories gave rise to the “mechanist conception of scientific explanation” defended by Machamer, Darden and Craver (2000), Bechtel and Abrahamsen (2005), Glennan (1996), etc., a conception increasingly debated among philosophers of science. Proponents of this conception claim that science (except fundamental physics) consists in identifying mechanisms at various levels, constituted by specific entities with proper activities, connected in a way that explains the typical outputs of the mechanisms. This approach promises to reduce traditional issues about causation to a clear and well-understood basis. One important advantage consists in thus treating all sciences above fundamental physics on the same ground – while the traditional view saw the whole of physics as the primary level, as the place where all the essential issues proper to science are raised.

Recently, though, the approach in terms of counterfactuals has been revisited in a way properly fitting the reality of causal reasoning in science, namely in Woodward’s (2003) manipulationist approach, according to which, if X and Y are two variables, X causes Y iff there exists an intervention on X that by itself changes Y's value. Woodward elaborated on Pearl (2000), a more formal approach to causation, using concepts from the theory of Bayesian nets. Among philosophers of science this account has been quickly adopted, for example in population genetics (Waters, 2005).

So, what is needed now is to assess those two important accounts of causation in philosophy of science, that are grounded on very different metaphysical approaches, that is, to evaluate the mechanicists' claim about the reducibility of causal issues, and to assess the applicability of those theories to various scientific fields. In this regard, the question is even raised whether the concept of causation is really univocal, or whether it should be splitted into two essentially different concepts, as Hall (2004) claimed by distinguishing causation by production from causation by dependence.

C. Multi-level causation.

Many scientific domains give explanations of the behavior of ensembles of individuals that are causally interacting with each other: statistical mechanics, dynamics of fluids, population genetics, sociology, ecology, etc. How are we to conceive of such explanations that refer to macro-properties of these ensembles, and how are they related to the causality at the micro-level? Macro-states can be realized at the micro-level in diverse ways (e.g. several distributions of molecules will be considered

equal in terms of entropy/energy, several prey-predator interactions are equivalent in terms of the differences of relative fitness of the types, etc.). What is the impact of this multi-realizability on the possibility of explaining processes at the macro-level? These questions, which encompass classical problems of reduction and emergence, are nowadays very actively studied in philosophy of science: elucidating the relative autonomy and the dependency of higher-level explanation is crucial in natural and social sciences and indeed in the philosophy of mind.

As far as social sciences are concerned, Jackson and Pettit (2002) forged the idea of "structural explanations" and claimed that the independence of those explanations from the behavior of the individuals relies on the "program" character of those explanations, i.e., some social structures dispose an ensemble of individuals as a whole to exhibit a specific behavior.

What is the role of probabilistic notions when several levels of causation are potentially involved? They are often used when the relevant system is constituted by a great amount of homogeneous components locally interacting in a simple way (in such cases the prediction of the future asymptotic macro-state is available up to a certain probability). But this method is not at hand in the case of fewer, inhomogeneous elements. There are cases where the future macroscopic behavior of the system cannot be predicted except by following or simulating step by step the development of successive micro-states. This absence of possible shortcuts, that characterizes "diachronic emergence" of the macro-properties, is actively investigated (Bedau (1997), Dubucs (2006, 2008)).

While the distinction between probabilistic and simulationist methodologies for studying complex system is of course important, a systematic study of their respective domains of application is still wanting. Strevens (2003) found that some specific structures of ensembles, characterized by the lessening of degrees of freedom (mostly by "compensating" independent opposite motions), allow the use of probabilistic concepts through the possibility of averaging out differences. This approach, rather than trying to understand causation in terms of probability, proceeds the other way round; it looks for the causal strictures that enable us to use probabilities in apprehending population behavior. Discussing this approach, while fundamental to an understanding of the possibility of conducting causal explanations at higher levels, provides also another entry to issues of probabilistic causation.

D. The objective reality of causality

As the discussion above makes clear, the notion of causation is crucial to science in general as well as to our understanding of central notions like that of scientific explanation. Therefore, the question arises what kind of objective reality causality has, how precisely one may understand the claim that causality really exists in the world. Obviously, how one answers the question depends on one's preferred analysis of causation. But it can also be tackled directly.

The main positions concerning the objective reality of causality are the following. First, one may deny that causality is a mind-independent feature of reality at all – as powerfully suggested by Hume's inductive skepticism and his criticism of causal necessity. Hume's point is still not convincingly refuted and sometimes even endorsed, e.g. by Putnam 1983. Somewhat more moderately, one might apply constructive empiricism (according to which we cannot know anything about unobservable entities and phenomena) to causal claims, and grant at best empirical adequacy, but no deeper reality to the causal claims of scientific theories, as van Fraassen (1980, pp. 112ff.) explicitly did.

Second, the majority of causal theories, of course, claim the mind-independent, i.e. objective reality of causality, even if they diverge otherwise. So do, e.g., the transference or conserved quantity approach (Salmon 1984, Dowe 2000), Armstrong's (1997) and Tooley's (1987) second-order universal

approach to laws and causation, Woodward's (2003) interventionistic approach, and Lewis' counterfactual analysis (concerning the latter the claim is completed only by Lewis' (1994) doctrine of the Humean supervenience of counterfactuals and probabilities on particular facts, the success of which is vigorously disputed).

Third and more interestingly, there are intermediate positions on the objectivity of causation. Williamson (2005), although sticking to an epistemic notion of causation, strives for objectivity through his objective Bayesianism. The most frequent intermediate position is projectivism that may plausibly be attributed already to Hume, that is definitely found in Kant and his peculiar construal of objectivity, and that is nowadays most prominently defended in Blackburn's (1993) quasi-realism. Spohn (1993, forth. a) and Ward 2002, 2005) try to explicate that projectivism in their own way. Another intermediate position that is hotly debated is structural realism asserting that we can only come to know what scientific theories tell us about the structures or relations between entities in the world, but cannot know anything about the substance (or nature) of those entities (cf., e.g., Worrall 1989, Ladyman 1998, Psillos 1999, 2001). A relevant quote is by van Fraassen himself: "the causal net = whatever structure of relations science describes" (1980, p. 124), although he would not subscribe to the realism about structures.

Besides differences in detail, this is probably the most profound issue over which causal theorists are deeply divided. As a philosophical enterprise our project would be badly incomplete without addressing this issue.

2.2. Own Preparatory Work

A. Actual Causation

As mentioned, Spohn (2006) is a recent contribution dealing with actual causation from the ranking-theoretic point of view. It contains a comparative discussion of the counterfactual analysis of causation and argues to more adequately deal with cases of symmetric overdetermination and preemption by trumping, but it does not offer anything that could be called a systematic comparison.

This paper must be read on the background of Spohn (1990), a much earlier twin paper on actual causation in the probabilistic setting, in a way the first elaborate treatment of the topic. It develops the issue much more systematically and in particular contains a careful argument concerning the transitivity of actual causation, one of the focal issues also of the present discussion. So, it has a lot of bearing on the present discussion that has not yet been elaborated so far.

Both papers originate from the Habilitation thesis of Spohn (1983) that unfortunately remained unpublished that contains many considerations being still valuable in the present discussion.

Besides, Spohn is continuously supervising doctoral and master theses, some of which are in the vicinity of this topic. Kleyer (2006) was most pertinent, but Bigliardi (2008) is contributing as well.On the French side, work has been done (Dubucs 1993b and forthcoming) on the formal properties of probability increase that are problematic in such a frame (e.g. contraposability) and possible ways of overcoming them. Isabelle Drouet has written her Master thesis (2004) on the propensity interpretation and she defended her PhD thesis (2007) under Dubucs' supervision on the philosophy of Bayesianism. Her recent paper (2007) on Bayesian nets and causal inference addresses to a central problem of the project.

B. Counterfactual vs mechanistic accounts of causality

The family of counterfactualist theories of causation has been apprehended by several members of the Paris group with a particular interest in dispositional concepts, which essentially include counterfactual views of causation.

Barberousse (2007) made an investigation of dispositional explanations by focusing on the physical concept of specific heat.

Isabelle Drouet PhD thesis contains an assessment on the relative abilities of counterfactualist and probabilistic theories of causation to account for dispositional statements that are pervasive in science – testing to some point Hitchcock's assertion of the coextensivity of counterfactualist accounts and statistical accounts of causation.

Kistler (1998; 1999a; 1999b; 2001; 2002a; 2002b; 2006) has argued for a conception of causation based on physical transmission of conserved quantities, improving on the accounts of Fair, Dowe and Salmon. He showed how such an amended transference account can be completed with the requirement of lawful dependence among other properties of causally interacting systems and argued that only a combination of the requirements of transference and lawful dependence can possibly account for all problem cases encountered in the literature. In recent work (presented to the 2007 SPS conference in Geneva) he shows that Glennan's (1996) claim is untenable according to which the notion of causation in its very generality can be reduced to the notion of mechanism.

Moreover, mechanism theories of science are under collective focus of the Paris team since a few years, as shown by the recent symposium of the *Société de Philosophie des Sciences* (Geneva, *to appear*). In the same vein, Huneman is editing at *Synthese Library (Springer)* a book called *Functions: Selection and Mechanism*, that include various contributions, assessing the value of etiological theories of functions and confronting them to the mechanism account of science, in order to capture the nature and specificities of functional explanations in various sciences.

On the German side, Spohn (1990, 2001, 2006) are relevant contributions, explicitly critical towards the counterfactual approach. Spohn, though, also asks what holds a mechanism together and argues that mechanistic conceptions seem to turn again on an analysis of direct causation and are thus unable to provide a reduction of the notion of causation. The conference "Current Issues of Causation" In Konstanz 1998 partly dealt with the issues, resulting in Spohn et al. (2001). Fahrbach (2005) and Kleyer (2006) are relevant work of students and collaborators of Spohn. He is presently supervising a dissertation by Alexander Reutlinger on causal explanations and ceteris paribus laws that will extensively deal with the interventionistic approach.

All these research activities naturally involve extensions toward a mutual understanding of counterfactualist/manipulationist versus mechanisms theories of science.

C. Muli-level causation

The research group on functional explanations at the IHPST currently deals with issues raised by functionalism in psychology or social sciences and with explanations at several levels in wholes composed of parts.

Kistler (2006) has suggested a conceptual framework in which a form of "downward" causation appears to be compatible with a physicalist framework. Higher-level "system laws" act as constraints on the evolution of complex systems that restrict the possible evolution of its microscopic parts.

Raidl has started his PhD thesis in September 2007 under Dubucs' and Spohn's joint supervision on problems narrowly related to the application of probability to multi-level causality.

Above all, the concept of emergence in complex systems has been under scrutiny by members of the IHPST since several years (Barberousse 2000, 2002 and 2003, Dubucs 2006, Huneman, Imbert 2007). Humphreys' research stay in Paris in 2006 has had a catalyst role in developing that line of research at IHPST. Imbert's PhD thesis (supervised by Dubucs) is exactly in the same perspective. It results in an edited volume of dynamic emergence (*Minds and Machines* forth 2007) that include contributions by Dubucs, Humphreys, and Huneman. This research has been also partly presented at the PSA symposium (Vancouver 06 – publication www.philsci.org), where Huneman compared whole-parts or mereological accounts of emergence to concepts based on computational principles providing a non-epistemic meaning of emergence. Humphreys (2004) is a reference book on precisely the new epistemological configuration arising by the pervasive use of computer simulations in science, a work on which views of computational emergence partly rely. This research stimulated to inquire in a new way the idea that, e.g., thermodynamics emerges from statistical mechanics. Moreover, the two conferences "Models and Simulation" organized by IHPST (Paris, 2006, with the London School of Economics; Tilburg, 2007, with the Department of Philosophy of Science of this University) provide further European entrenchment for this work.

D. The objective reality of causality

Spohn (1993) is one of the two recent attempts to state and formally elaborate an intermediate position concerning the objective reality of causality, i.e., a constructive realization of what has been called (Humean) projectivism. Spohn (forthcoming *a*) extends this to a projectivist account of objective probabilities, criticizing at the same time their alleged Humean supervenience. These papers must also be seen in its relation to Spohn (1997) and (2002) that indicate how it might work first to postulate, e.g., unobserved bases of dispositions in order to account for their observed manifestations and then to objectivize these posits by ever better specifying the ceteris paribus clause necessarily accompanying the first postulation. How all this adds up to an embracive alternative to David Lewis' Humean supervenience is more fully explained in Spohn (in preparation, ch. 12-15).

Again, relevant work produced at the chair and under the supervision of Spohn are Fahrbach (2002) (a dissertation on Bayesianism), Dudau (2003) (a dissertation on realism and antirealism in the philosophy of science in general, Rosenthal (2004) (in our view presently the most careful critical discussion of objective interpretations of probability), and Bigliardi (2008).On the French side, Morganti has a piece of work (2004) just on that question, while Kistler (2005) has proposed a refutation of Putnam's (1987, 1992) argument against the reality of causation.

3. Aims and Working Program

3.1. Aims

The general aim is to make progress on the four topics that, as explained, have proved to be of particularly urgent interest in the current discussion. The progress is to be achieved at the level of the individual projects in the first place (see the individual subsections). But is to be essentially advanced

through a close and beneficial cooperation between the projects (for details of the organization of the cooperation see section 3.2).

We believe that the progressive potential of the projects lies in their comparative nature. The main characteristic of the present situation, which is as problematic as fascinating, is the confusing multitude of approaches to causation. This character would not change by further developing the individual approaches; that would simply leave the basic situation unresolved. Our way of proceeding, we are convinced, is more effective. Subproject A is comparative by investigating how various approaches deal with a specific central problem, the notion of actual causation. Subproject B is comparative by inquiring the relation between two prominent approaches, the counterfactual and mechanistic one. Subproject C is comparative in a different sense by studying how we can have causal relations on different levels and how these causal relations can be fitted together. Subproject D, finally, is comparative, since it addresses what the various approaches have to say about the fundamental philosophical issue of the objectivity of causality.

It is precisely the comparative nature of the projects that opens up fruitful ways of cooperation. Thereby, they are intertwined in jig-saw-puzzle like way. This is obvious for the subprojects A and B; part B takes up two main conceptions of causation on a broader scale that at the same time are among the main candidates concerning actual causation treated in part A. But it applies to part C as well, since it treats the question on the basis of which account we can understand several, i.e. micro and macro levels of causation and their relations. The projects are methodologically integrated insofar as probabilistic methods are crucial for all of them (as explained already in section 2.0). Part D, finally, is intended as a philosophically over-arching project providing philosophical reflection on what the other subprojects are about; for all them the issue of the objectivity of causation is basic and may have specific repercussions. For details of the intended lines of cooperation see section 3.2.

Deliverables and Milestones:

We would definitely assess our joint project as successful, if we would manage to deliver the following items:

– About three papers in journals or collections in each subproject. This might be less or should be more depending on the following point.
– A research monograph in each subproject would be desirable. It is to be expected in the subprojects with one main researcher, say, a dissertation in part A and a monograph in part D; in the more collaborative subprojects B and C it might also be a focal collection of essays as a book or a special issue of a relevant journal.
– A joint conference or a summer school with the accompanying proceedings.
– A number of workshops, ideally one for each subproject, either in Konstanz or in Paris or associated with the big congresses of the European Philosophy of Science Association or the Gesellschaft für Analytische Philosophie.
– Some successful presentations at relevant conferences.

This is demanding, but appears manageable. In any case, these are our milestones we aim at. Of course, not all publications can be expected to have appeared or even accepted at the end of the project. For more details see section 3.2.

A. Actual causation

In section 2.1 we mentioned that for the first time in the history of the subject we have several theories of actual causation at our disposal that are based on different background theories of causation (probabilistic, structural-model, counterfactual, ranking-theoretic, etc.), and that, unlike the historic predecessors, try or claim to account for all the riddles of causation presented by overdetermination, various forms of preemption, various forms of prevention, structural intuitions, etc. This richness has emerged only in the last years, the final pieces being very recent. There does not yet exist a systematic overview and comparison of all these approaches, weighing their relative strengths and merits. To provide such a comparison in a philosophically reflected and formally sound way would be of utmost importance. This is the primary aim of this subproject. Of course, the subproject should not remain on the descriptive-comparative level. The deeper aim is that one of the approaches can be argued to be superior to the others, that this approach can perhaps be amended by ingredients from the other ones, and that in this way one of the background philosophies may get confirmed. Such an argument should be forthcoming, though, of course, it can presently not be predicted what it will be. The idea of a "reference book" on the topic is envisaged.

This subproject has a large overlap with part B; whatever its results, they are most relevant to a more general evaluation of counterfactual and mechanistic accounts. Reversely, work on part B will serve as a valuable check for this subproject. Again, the comparison on actual causation needs to be put in perspective with the results of subproject D. Whatever incoherencies might turn up, they need aligning.

B. Counterfactual vs mechanistic accounts of causality

Here, the aim is to evaluate recent proposals (by Woodward 2003 and at a more metaphysical level, Keil 2000) to construe causation by means of counterfactual interventions, or manipulations. It is to be seen in how far these accounts can cope with traditional objections against both counterfactual and manipulabilistic accounts. A particularly important aspect of the inquiry is to evaluate their ability to account for experimental techniques that seem to cross levels of organization. In bottom-up interventions (see e.g. Craver 2007), one intervenes on a part of a mechanism and checks the resulting change in parameters at the level of the whole system. In top-down experiments, one puts a mechanism to work on a specific task and observes the changes this produces at the level of its parts. Manipulabilistic accounts of causation would seem to have to conclude that there is causation across levels. It has to be seen whether this consequence is acceptable (Huneman, Kistler).

Then the extension of mechanistic explanations will be discussed, for example by asking whether population level systems like ecosystems can be thought of as mechanisms. More precisely, is it possible to treat natural selection as a mechanism? And generally, are stochastic devices (like in Diaconis 2005) likely to be thought of as mechanisms on a par with deterministic systems? (Barberousse and Drouet will work on stochastic mechanisms, Huneman on natural selection). Secondly, we will discuss the range of manipulabilistic conceptions of science: it is obviously applicable to genetics (knocking out genes, etc) or to quantum electrodynamics. But how is it pertaining to social sciences – i.e., how is "intervention" to be conceived in order to make sense of interventions on social or economic variables, given that those variables are not at the same level? More generally, is the manipulabilistic conception of science likely to capture the nature of "generative social science", which involves "agent-based" models (Epstein and Axtell, 1997). Humphreys, relying on previous work in the philosophy of eco-

nomics, will deal with this issue. This research will also rely on previous work done at the IHPST on the epistemology of simulations (symposiums “Models and simulations” (the first one co-organized with LSE in 2006 (Humphreys, Imbert, etc. among the speakers), the second one co-organized with Tilburg Department of Philosophy of Science in 2007)

C. Multi-level causation

Philosophers of various fields in our project will articulate the specificity of multi-level causation in their domain, highlighting the variety of explanatory strategies conducted in various cases. This will ground our attempt of a general view of multi-level causation. Such attempts will rely on the previous examination of the mechanisms/counterfactual alternative in philosophy of science, for mechanism-style theories of science emphasize the difference between intralevel explanation, which are causal, and interlevel explanations, which are “constitutive” (Craver and Bechtel 2006) ((Huneman and Kistler will handle those issues).

The other approach will rely on previous work made on emergence. We shall compare views of emergence as computationally defined in simulations, and those as properties of wholes irreducible to properties of the lower-level parts of which they are composed. The main issue will involve questions about how one shifts from definitions of emergence within a simulated system to emergence in the system that is simulated – hence issues in computation and simulation (Huneman, Humphreys, Dubucs).

The previous issue, already studied at the IHPST for biology, will also be analyzed (Barberousse, Imbert) in physics by the comparative study of simulations of turbulent fluids made at different causal levels (particle level vs. velocity field level). A close systematic comparison will be carried out between the study of turbulence by discretization of Navier-Stokes equation and its mere simulation by cellular automata. Only from such fine-tuned analyses philosophical lessons can be drawn about levels of causal interaction.

The analysis of auto-organization phenomena in terms of multi-level causation is also a promising direction after the failure of other approaches. What types of causal interactions are required at different levels for a system to auto-organize? Barberousse and Imbert shall study this question at examples taken from different fields, namely the formation of Bénard cells in fluid dynamics, the setting of avalanches and the emergence of organisms from unicellulars to proto-organisms.

Finally, such an interdisciplinary approach of multi-level causation will allow us to discuss, assess and refine Strevens (2003) investigation on the foundations of sciences of complex systems, by introducing a more sophisticated understanding of the requisites to be satisfied by the various sciences.

D. The objective reality of causality

We mentioned that the topic is around since Hume’s famous criticism of causal necessity. Since, it has tremendously ramified. The main problem with the existing literature is that all authors are aware of the topic and are very opinionated on it. Either the stance to take is obvious and diverging opinions don’t need serious attention, or it is so complicated that less complicated opinions simply can’t be adequate. Thus, there is little comparative discussion. We know of no comparative monograph that addresses the topic straight ahead. The central aim of the project is to close this gap.

Part of the comparative work is to include the discussion about the objective interpretation of probabilities as chances or propensities. The parallel is quite clear. There is the general idea of determina-

tion that may be full, i.e., necessitation as in the case of sufficient causation or only partial as in the case of propensities. In both cases the issue is how to gain an objective or ontological understanding of determination; and whatever is argued to be a reasonable position concerning causation should be one concerning probability, and vice versa. This parallel harbors little used, but rich resources of comparative discussion.

No doubt, this is a philosophically very demanding project; one has to be acquainted with the historical and the current systematic depth of the topic with respect not only to causality, but also to probability. It would already be a most valuable gain to set out the various positions and their relations in a lucid and precise way, so that everyone is clear what he affirms and denies by taking one and rejecting the other positions. This has to be accomplished in this subproject in any case. Moreover, it would be desirable that the clear exposition also leads to a well-founded preference among the available positions. Whether it does and what the preference might be is, however, presently unpredictable.

As already mentioned, this part provides philosophical foundations for all the other subprojects. Precisely for this reason it reversely depends on a coherence check with the other projects.

3.2. Working Program, Methods, Schedule

How the cooperation between IHPST and the Department of Philosophy in Konstanz is to be realized

We have thoroughly explained that the collaboration between the two centers is required, feasible, and fruitful not only mutually, but also within the European context and that it meets a most supportive background. Before turning to the subprojects, let us state how we intend to organize the close cooperation between the two centers. The means we are applying for in order to realize the cooperation are specified in section 4.

- Each subproject will organize a workshop specific to its topic at which at least parts of the partner lab will participate.
- An international conference or summer school on “Probability and Causality” will be organized probably in 2011 (the details of organization are taken over by IHPST with the help of its greater administrative staff).
- The collaborators plan to have about three additional internal working meetings for presenting and discussing the progress within the subprojects.
- Each post-doc employed in the program is supposed to visit the partner lab once or twice a year.
- Each PhD student involved in or associated to the project should stay at least 3 months (within the three years of the program) in the partner lab.
- The dates of these events and travels have, of course, to be jointly agreed by the supervisors of the PhD theses and of the coordinators of the program. Incidentally, funds will be kept and used to send PhD students and post-docs at relevant workshops and conferences, even if they don’t submit papers, in order to increase their philosophical and scientific background.
- We plan a common website in order to exchange primary sources and papers in progress, as well as to disseminate results of scientific activity. It is in charge of IHPST, since it will have a permanent webmaster from other sources.
- The coordinators of the program will subscribe to electronic journal of sources if required by their program and not yet available.

A. Actual causation

Two thirds of the working program are straightforward: (1) the pattern of questions and desiderata must be established under which all of the competing theories are to be assessed, basic intuitions, recalcitrant examples, theoretical and structural properties, etc. These can be directly collected from the relevant literature. (2) – (5) each of the four competing theories (or more) have to be carefully inquired under this pattern of questions and desiderata. Often the authors give the answers by themselves, often they do not. To this extent, the theories must be elaborated within the project. (6) A well-considered summary and conclusion can and should be drawn from all this work. Each of the six steps should be achieved roughly within four months. This adds up to two years. Then follows the unpredictable last third. It is most unlikely that the conclusion will be that one account is just fine and the others are not. Rather, one will presumably be relatively best and can somehow learn from the good insights of the others. Another six or eight months before summing up the research should suffice to make substantial progress on the existing debate. Since this subproject is most closely related to subproject B, it will have to proceed in continuous exchange with that subproject.

This subproject is demanding, but to a large extent well-defined, a perfect program for a Ph.D. student who is already well acquainted with the field, the required formal methods, and the prevailing argumentative standards.

Deliverables and milestones for this subproject are: a thesis at the end of the project, in addition two or three papers in journals or collections, organization of a workshop, participation at the regular meetings and at further conferences.

B. Counterfactual vs mechanistic accounts of causality

The first part of the program will develop applications of the mechanistic model of science to particular fields – Huneman on ecology and genetics; Barberousse, Morganti, and Kistler on thermodynamics; Drouet, Dubucs, Humphreys, and Spohn on economics. This will allow us to answer the questions from section 3.1 about what kind of explanandum system can be treated as a mechanism. B. A first 2-days workshop (fall 2009) will settle the methodology and present first results in various fields.

The second part of the program – led by Huneman, Kistler, and Dubucs – will consider recent applications of Woodward's manipulabilistic account as they have been elaborated in several domains: evolutionary theory of development (Love 2996), genetics (Waters 2005), economics (Cartwright, Woodward) We shall evaluate those accounts and confront them to the received views of explanation that they challenge. This will lead us to a detailed account of what "intervention" can mean in various sciences. A second 2-days workshop (spring 2010) will bring together those views.

The third part of the program, then, will consist in merging the results of those inquiries in order to gain a more specific view of causation and causal explanations in the variety of sciences; a final symposium (end of 2011) will be the outcome, and give rise to a collective book (of course, drafts and works in progress should have been previously exchanged and discussed among all the participants of the program.

C. Multi-level causation

The first part of this subproject requires reviewing the on-going debate about whether “upward“ and “downward” causation are conceptually coherent and acceptable from a physicalist standpoint. Kim in particular has argued that it is not. Kistler will lead this work. In a further step, we will examine whether recent advances in the analysis of the notion of emergence can help make progress in assessing whether higher-level properties can have causal efficacy that goes beyond that of the underlying micro-properties.

Then we shall deal with issues about emergence in computer simulations. With the help of the Laboratoire d’Informatique Fondamentale de Lille, with which we use to collaborate on other research programs (e.g. two ANR inter-disciplinary programs, one on cooperation, the other one on the “computational turn in science” that have been just submitted or, in the past, ACI program on Emergence in Complex Systems), Imbert, Barberousse and Huneman will devise simulations (with social scientists and natural scientists) of population scale phenomena, and focus on the way rules are forged and prescribed to the agents in a cellular automaton or in an agent-based model, where there does not exist a formalized underlying theory of the domain. Cases where different sets of rules yield the same outcomes will be pointed out, and the team will investigate the philosophical consequences of those situations for the nature of causal explanation in simulated complex systems. Beyond local workshops, those issues on emergence will give rise to a symposium in 2009 or 2010 and a special issue of a journal in the field (e.g. *Synthese*).

The last section of the project will highlight the specific nature of the conditions of understanding complex systems as they are found in thermodynamics (Barberousse), in the sciences involving natural selection (Huneman), and in the social sciences (Humphreys, Dubucs). The question raised here is: are the uses and modes of probabilistic thinking as a description or explanation of systems the same across all disciplines, or are there essential differences dictated by the ontological status of the domains involved? This third question will be the final outcome of part C, and it will give rise to a self-contained volume (Springer – *Logic, Epistemology and the Unity of Science Series*).

D. The objective reality of causality

The working program is in a way straightforward. There is a spectrum of positions on the objectivity of causality. It is perhaps difficult to take serious those positions that simply deny the objectivity of causation and do not offer any substitute (although one must look also at their arguments). All the other positions may perhaps be ordered according to their attitude towards the epistemology and the ontology of causation. There is the minority (Williamson 2005) denying the ontological aspect and seeking objectivity purely on the epistemological side (via the rationality of belief formation). The rest is divided over the priority of ontology and epistemology. The standard objectivists, who come in many forms (Lewis 1973 and thereafter, Salmon 1984, Spirtes et al. 1993, Woodward 2003, Machamer 2004, etc.), give priority to ontology; first of all, causal relations, however they are to be analyzed, are out there and remain to be discovered. These objectivists then have to tell an epistemological story how we can find out about the objectively given causal relations, how we can confirm and disconfirm them; that’s not so easy. The intermediate positions, neither purely subjectivist nor straightforwardly objectivist (like Gärdenfors 1988, who denies objective truth conditions and defines assertibility conditions for counterfactuals, Blackburn 1993, Spohn 1993, forthcoming a, Ward 2002, 2005), conceive causation as a somehow tacit epistemological concept; they have conversely to tell an ontological

story how causal relations can acquire an objective and independent existence on this basis. Projectivism is a key word, but so far only a metaphor.

Likewise, there is spectrum of positions on the objectivity of probability that perhaps need not be rehearsed at this place. Thus, there is a matrix of actually maintained positions. The relations on the causality side need to be elaborated as well as the relations on the probability side. There will be a considerable match. This should be most revealing. There is perhaps also a mismatch between the two sides; a comparison of the two sides may show that to some extent good analogues to the one side do not exist at the other side. Does closing the gaps lead to interesting positions? This is an open question. And so forth. In the required brevity we can only appeal to the plausibility of the fact that the indicated matrix entails a rich and well-ordered working program that has not been carried out so far and the elaboration of which will be most illuminating.

This subproject will considerably profit from the collaboration between the two centers, since the French side can richly contribute by Morganti on the topic of scientific realism in general, Kistler on the topic of the mind-dependence of causality, Dubucs on objective probabilities, Drouet on Bayesian nets and Raidl on symmetry in probability.

Deliverables and milestones for this subproject are: a research monograph at the end of the project, in addition two or three papers in journals or collections, organization of a workshop, participation at the regular meetings and at further conferences.

6. Presuppositions of the Project

6.1. Composition of the Working Group

The working group at the IHPST consists of: Jacques Dubucs (Senior Scientist, CNRS, Head of IHPST, coordinator), Dr. Anouk Barberousse, Junior Scientist (CNRS), Mikael Cozic (Post-Doc), Brian Hill (Associate Professor, GREG-HEC) Philippe Huneman, Junior Scientist (CNRS), Max Kistler (professor, Pierre Mendès France University, Grenoble), Matteo Morganti (Post-Doc), Isabelle Drouet (Post-Doc), Cyrille Imbert (PhD student), Eric Raidl (PhD student). It is supplemented by Prof. Paul Humphreys (University of Virginia).

The working group at the Universitiy Konstanz will consist of Prof. Wolfgang Spohn (director) and the two collaborators (N.N., N.N.). Further local cooperators are Prof. Gereon Wolters (philosophy of science), Alexander Reutlinger and Stefan Hohenadel (Ph.D. students) and in particular Dr. Franz Huber and the Emmy Noether research group “Formal Epistemology” directed by him at the University of Konstanz. It will be supplemented by Prof. James Woodward.

6.2. Cooperation with other Scientists

The History and Philosophy of Science Department of the University of Pittsburgh is a long-standing official partner of the Philosophy Department in Konstanz. There exist also close contacts with Clark Glymour, Peter Spirtes, and Richard Scheines from the Carnegie Mellon University, the main proponents of a Bayesian net theory of causation. The project will be further strengthened on the European level by the following persons who are most pertinent to the projects and have all agreed to cooperate:

Prof. Luc Bovens, Department of Philosophy, Logic, and Scientific Method, London School of Economics,

Prof. Stephan Hartmann, Tilburg Center for Logic and Philosophy of Science, University of Tilburg

Prof. Paul Humphreys, Department of Philosophy, University of Virginia, USA

Prof. Stathis Psillos, Department of History and Philosophy of Science, University of Athens.

References to Works of the Participating Collaborators

Barberousse, Anouk (2000), *La physique face à la probabilité*, Paris: Librairie Philosophique Vrin.

Barberousse, Anouk (2002), *La mécanique statistique de Clausius à Gibbs*, Paris: Belin.

Barberousse, Anouk (2003), "The Diversity of Models in Statistical Mechanics. Views about the Structure of Scientific Theories", in B. Löwe, W. Malzkorn & T. Räsch (eds.), *Foundations of the Formal Sciences II, Applications of Mathematical Logic in Philosophy and Linguistics*, Kluwer, pp. 1-24.

Barberousse, Anouk (2007), "Are There Specific Heat Dispositions?", in M. Kistler & B. Gnassounou (eds.), *Dispositions and Causal Powers*, Ashgate, pp. 271-282.

Barberousse, Anouk, P. Ludwig (2000), "Les modèles comme fictions", *Philosophie*, 68.

Bergt, Tilman (2004), *Die Relevanz von Theorien der Überzeugungsänderung für das Problem der Rationalität induktiver Schlüsse*, MA-Arbeit Universität Konstanz.

Bigliardi, Stefano (2008), *Introduction to the Ranking Functions Theory*, unpublished doctoral thesis, Università degli Studi die Bologna (supervised by Wolfgang Spohn).

Drouet, Isabelle (2004), *La théorie propensionniste des probabilités*, Master Thesis, IHPST.

Drouet, Isabelle (2007), *Causalité et probabilités: réseaux bayésiens, propensionnisme*, unpublished doctoral thesis, IHPST (supervised by Jacques Dubucs).

Drouet, Isabelle (2007), "Causal Inference. How Can Bayesian Networks Contribute?", in F. Russo & J. Williamson (eds.), *Causality and Probability in the Sciences*, College Publications, Texts in Philosophy Series, n° 5, pp. 487-501.

Dubucs, Jacques (ed.) (1993a), *Philosophy of Probability*, Dordrecht: Kluwer.

Dubucs, Jacques (1993b), "Inductive Logic Revisited", in Dubucs (1993a), pp. 79-108.

Dubucs, Jacques (2002), "Simulations et modélisations". *Pour la Science 300*, pp. 156-158.

Dubucs, Jacques (2006), "Unfolding Cognitives Capacities", in M. Okada et al. (eds.), *Reasoning and Cognition*, Keio University Press, pp.95-101.

Dubucs, Jacques (forth.), "Causality, Probabilities, Propensities", in M. Suarez (ed.), *Probabilities, Causality and Propensities in Physics*, special issue of *Synthese*.

Dudau, Radu (2003), *The Realism/Antirealism Debate in the Philosophy of Science*, Berlin: Logos-Verlag.

Fahrbach, Ludwig (2002), *Bayesianismus und naturalisierte Erkenntnistheorie*, Berlin: Logos Verlag.

Fahrbach, Ludwig (2005) "Understanding Brute Facts", *Synthese*, vol. 145, 3, 449-466.

Haas, Gordian (2005), *Revision und Rechtfertigung. Eine Theorie der Theorieänderung*, Heidelberg: Synchron.

Humphreys, Paul (1989*), The Chances of Explanation: Causal Explanation in the Social, Medical, and Physical Sciences*.Princeton University Press.

Humphreys, Paul (2004), *Extending Ourselves*, Oxford: Oxford University Press.

Huneman, Philippe (forth.), "Emergence and Adaptation", *Minds and Machines*, Special issue, "Dynamic Emergence".

Huneman, Philippe. (forth.), "Compositional vs. Combinatorial Emergence", *PSA Meeting* 2006 (www.philsci.org), Phil Sci 2008.

Huneman, Paul (Submitted), *Natural Selection as a Cause and as Explanation.*

Huneman, Philippe (ed.), (In preparation) *Functions: selection and mechanisms.* Synthese Library, Springer.

Imbert, Cyrille (2007), "Why Diachronically Emergent Properties Must Also be Salient", in C. Gershenson, D. Aerts & B. Edmonds (eds.), *Philosophy and Complexity: Essays on Epistemology, Evolution and Emergence*, World Scientific Publ., 2007, pp. 99-116.

Kistler, Max (1998), "Reducing Causality to Transmission", *Erkenntnis* 48, pp. 1-24.

Kistler, Max (1999a), *Causalité et lois de la nature*, Paris, Vrin. (English version: Causation and Laws of Nature, London, Routledge, 2006).

Kistler, Max (1999b), "Causes as Events and Facts", *Dialectica* 53, pp. 25-46.

Kistler, Max (2001), "Causation as Transference and Responsibility", in Spohn et al. (2001), pp. 115-133.

Kistler, Max (2002a), "Erklärung und Kausalität", *Philosophia Naturalis*, 39, Heft 1, pp. 89-109.

Kistler, Max (2002b), "Causation in Contemporary Analytical Philosophy », *Quaestio-Annuario di storia della metafisica*, vol. 2, éd. C. Esposito et P. Porro, Turnhout (Belgique), Brepols, pp. 635-668.

Kistler, Max (2004), "La causalité dans la philosophie contemporaine", *Intellectica*, 38, 2004/1, pp. 139-185.

Kistler, Max (2005), "La rationalité et la causalité dans le réalisme interne de Putnam", *Philosophie* 85, pp. 62-92.

Kistler, Max (2006), "La causalité comme transfert et dépendance nomique", *Philosophie* 89, pp. 53-77.

Kleyer, Tobias (2006), *Die kontrafaktische Theorie der Kausalität*, unpublished Master Thesis, Department of Philosophy, University of Konstanz.

Morganti, Matteo (2004), "On the Preferability of Epistemic Structural Realism", *Synthese*, 142-1, pp. 81-107.

Rosenthal, Jacob (2004), *Wahrscheinlichkeiten als Tendenzen. Eine Untersuchung objektiver Wahrscheinlichkeitsbegriffe*, Paderborn: Mentis.

Spohn, Wolfgang (1980), "Stochastic Independence, Causal Independence, and Shieldability", *Journal of Philosophical Logic* 9, 73-99.

Spohn, Wolfgang (1983), *Eine Theorie der Kausalität*, unpublished Habilitationsschrift, University of Munich, available as pdf-file: http://www.uni-konstanz.de/FuF/Philo/Philosophie/Spohn/spohn_files/Habilitation.pdf

Spohn, Wolfgang (1990), "Direct and Indirect Causes", *Topoi* 9, pp. 125-145.

Spohn, Wolfgang (1993), "Causal Laws are Objectifications of Inductive Schemes", in: Dubucs (1993a), pp. 223-252.

Spohn, Wolfgang (1997), "Begründungen a priori – oder: ein frischer Blick auf Dispositionsprädikate", in W. Lenzen (ed.), *Das weite Spektrum der Analytischen Philosophie. Festschrift für Franz von Kutschera*, Berlin: de Gruyter, pp. 323-345.

Spohn, Wolfgang (2001), "Bayesian Nets Are All There Is To Causal Dependence", in: M.C. Galavotti et al. (eds.), *Stochastic Dependence and Causality*, CSLI Publications, Stanford, pp.157-172.

Spohn, Wolfgang (2002), "Laws, Ceteris Paribus Conditions, and the Dynamics of Belief", *Erkenntnis* 57, pp. 373-394.

Spohn, Wolfgang (2006), "Causation: An Alternative", *British Journal for the Philosophy of Science* 57, pp. 93-119.

Spohn, Wolfgang (forth. *a*), "Chance and Necessity: From Humean Supervenience to Humean Projection", in: E. Eells, J. Fetzer (eds.), *The Place of Probability in Science*, Chicago: Open Court.

Spohn, Wolfgang (in preparation), *Ranking Theory. A Tool for Epistemology* (ca. 650 pages).

Spohn, Wolfgang, Marion Ledwig, Michael Esfeld (eds.) (2001), *Current Issues in Causation*, Paderborn: Mentis.

Further References

Armstrong, David M. (1997), *A World of States of Affairs*, Cambridge: Cambridge University Press.

Bechtel, William and Adele Abrahamsen (2005), "Explanation: A Mechanist Alternative," in Carl F. Craver and Lindley Darden (eds.), Special Issue: "Mechanisms in Biology," *Studies in History and Philosophy of Biological and Biomedical Sciences* 36, pp. 421-441.

Blackburn, Simon (1993), *Essays in Quasi-Realism*, Oxford: Oxford University Press.

Bogen, James (2003), "Analyzing Causality: The Opposite of Counterfactual is Factual," rewritten version of PSA 2002 workshop paper, which is posted at University of Pittsburgh Philosophy of Science Archive, http://philsci-archive.pitt.edu.

Bogen, James (2005), "Regularities and Causality; Generalizations and Causal Explanations," in Carl F. Craver and Lindley Darden (eds.), Special Issue: "Mechanisms in Biology," *Studies in History and Philosophy of Biological and Biomedical Sciences* 36: 397-420.

Cartwright, Nancy (2000), *The Dappled World: A Study of the Boundaries of Science*, Cambridge University Press

Collins, John, Ned Hall, and Laurie A. Paul (eds.) (2004), *Causation and Counterfactuals*, Cambridge, Mass.: MIT Press.

Craver, Carl F. (2001), "Role Functions, Mechanisms, and Hierarchy," *Philosophy of Science* 68, pp. 53-74.

Craver, Carl and Lindley Darden (2001), "Discovering Mechanisms in Neurobiology: The Case of Spatial Memory," in Peter Machamer, R. Grush, and P. McLaughlin (eds.), *Theory and Method in the Neurosciences.* Pittsburgh, PA: University of Pittsburgh Press, pp. 112-137.

Craver, Carl F. and William Bechtel (2005) “Mechanisms and Mechanistic Explanation” in S. Sarkar and J. Pfeiffer (eds.), *The Philosophy of Science: An Encyclopedia.* Routledge Press.

Craver, Carl F. (2007), *Constitutive Explanatory Relevance*, manuscript.

Davidson, Donald (1985), „Reply to Quine on Events“, in: E. LePore, B. McLaughlin (eds.), *Actions and Events: Perspectives on the Philosophy of Donald Davidson*, Oxford, pp. 172-176.

Diaconis, Peter N. (2005), “Dynamical Bias in the Coin Toss”. With S. Holmes and R. Montgomery. To appear in *SIAM Review*.

Dowe, Phil *Physical Causation*, Cambridge University Press, Cambridge, 2000.

Ellis, Brian (2002) *The Philosophy of Nature: A Guide to the New Essentialism*, Mc Gill, Queen University Press.

Epstein, Joshua M. and Robert L. Axtell. 1997. *Growing Artificial Societies*, Cambridge: MIT Press.

Fair, David (1979), “Causation and the Flow of Energy”, *Erkenntnis* 14, 219-250.

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

Fraassen, Bas C. van (1989), *Laws and Symmetry*, Oxford: Clarendon Press.

Fraassen, Bas C. van (1998) “The Agnostic Subtly Probabilified” *Analysis* 58, pp. 212–220.

French, S. and Ladyman, J. (2003) “The Dissolution of Objects: Between Platonism and Phenomenalism”, *Synthese*, vol. 136: 73-77.

Gärdenfors, Peter (1988), *Knowledge in Flux*, Cambridge, Mass.: MIT Press.

Glennan, Stuart S. (1996), "Mechanisms and The Nature of Causation," *Erkenntnis* 44, pp. 49-71.

Glennan, Stuart S. (2002), "Rethinking Mechanistic Explanation," *Philosophy of Science* (Supplement) 69, pp. 342-353.

Glennan, Stuart S. (2005), “Modeling Mechanisms,” in Carl F. Craver and Lindley Darden (eds.), Special Issue: “Mechanisms in Biology,” *Studies in History and Philosophy of Biological and Biomedical Sciences* 36, pp. 443-464.

Hall, Ned (2004), “Two Concepts of Causation”, in: Collins et al. (2004), pp.225-276.

Halpern, Joseph Y., Judea Pearl (2005), “A Structural-Model Approach. Part I: Causes, Part II: Explanations”, *British Journal for the Philosophy of Science* 56, pp. 843-887 and pp. 889-911.

Hitchcock, Christopher R. (1995) "Salmon on Explanatory Relevance," *Philosophy of Science* 62, pp. 304-320.

Hitchcock, Christopher R. (2001), “A Tale of Two Effects”, *Philosophical Review*, pp. 361-396

Jackson, Franck and Pettit, Philip (2002) *Structural Explanation in Social Theory. Mind, Morality and Explanation*, Oxford: Oxford University Press.

Keil, Geert (2000), *Handeln und Verursachen*, Vittorio Klostermann, Frankfurt a. M.

Ladyman, J. (1998) “What is Structural Realism?”, *Studies in History and Philosophy of Science*, vol. 29: 409-424.

Lewis, David (1973), “Causation”, *Journal of Philosophy* 70, pp. 556-567.

Lewis, David (1986), “Causation”, in: *Philosophical Papers*, Vol. II, Oxford University Press, New York, pp. 159-213.

Lewis, David (1994), “Humean Supervenience Debugged”, *Mind* 103, pp. 473-490.

Love, Alan C. (2006), “Evolutionary Morphology and Evo-Devo: Hierarchy and Novelty”, *Theory in Biosciences* 124, pp. 317-333.

Machamer, Peter (2004), “Activities and Causation: The Metaphysics and Epistemology of Mechanisms,” *International Studies in the Philosophy of Science* 18, pp. 27-39.

Machamer, Peter, Lindley Darden, and Carl Carver (2000), "Thinking About Mechanisms," *Philosophy of Science* 67, pp. 1-25.

Pearl, Judea (1988), *Probabilistic Reasoning in Intelligent Systems: Networks of Plausible Inference*, San Mateo, Calif.: Morgan Kaufmann.

Pearl, Judea (2000), *Causality. Models, Reasoning, and Inference*, Cambridge: Cambridge University Press.

Psillos, S. (1999) *Scientific Realism: How Science Tracks Truth*, London: Routledge.

Psillos, S. (2001) “Is Structural Realism Possible?”, *Philosophy of Science* (Supplement), vol. 68: S13-24.

Putnam, Hilary (1983), “Why There Isn’t a Ready-Made World”, in: H. Putnam, *Realism and Reason. Philosophical Papers* Vol. 3, Cambridge: Cambridge University Press.

Putnam, Hilary (1987), The Many Faces of Realism, LaSalle, Ill., Open Court.

Putnam, Hilary (1992), Renewing Philosophy, Cambridge, MA, Harvard University Press.

Salmon, Wesley (1984) *Scientific Explanation and the Causal Structure of the World*, Princeton University Press.

Salmon, Wesley (1997) “Causality and Explanation: A Reply to Two Critiques”, *Philosophy of Science*, Vol. 64, No. 3 pp. 461-477.

Skipper, Robert A., Jr. and Roberta L. Millstein (2005), “Thinking about Evolutionary Mechanisms: Natural Selection,” in Carl F. Craver and Lindley Darden (eds.), Special Issue: “Mechanisms in Biology,” *Studies in History and Philosophy of Biological and Biomedical Sciences* 36: 327-347.

Sklar, Lawrence (1992), *Philosophy of Physics*, Westview Press, Boulder and Oxford UK: Oxford University Press.

Spirtes, Peter, Glymour, Clark, and Richard Scheines (1993), *Causation, Prediction, and Search*, Berlin: Springer.

Strevens, Michael (2003), *Bigger than chaos*. Harvard University Press.

Tooley, Michael (1987), *Causation*, Oxford: Oxford University Press.

Ward, Barry (2002), “Humeanism Without Humean Supervenience: A Projectivist Account of Laws and Possibilities”, *Philosophical Studies* 107, 191-218.

Ward, Barry (2005), “Projecting Chances: A Humean Vindication and Justification of the Principal Principle”, *Philosophy of Science* 72, 241-261.

Waters, C. Kenneth (2005) “Why Genic and Multilevel Selection Theories are Here to Stay”, *Philosophy of Science* 72 (2), pp. 311-333.

Williamson, Jon (2005), *Bayesian Nets and Causality*, Oxford: Oxford Unversity Press.

Wimsatt, William (1972), "Complexity and Organization," in Kenneth F. Schaffner and Robert S. Cohen (eds.), *PSA 1972, Proceedings of the Philosophy of Science Association.* Dordrecht: Reidel, pp. 67-86.

Woodward, James (1995), “Causality and Explanation in Econometrics." In *On the Reliability of Economic Models: Essays in the Philosophy of Economics*, ed. Daniel Little, Kluwer, pp. 9-61.

Woodward, James (2003), *Making Things Happen*, Oxford: Oxford University Press.

Woodward, James (forth.), “Experimental Investigations of Social Preferences”, *The Oxford Handbook of Philosophy of Economics*. Oxford University Press.

Worrall, John (1989) “Structural Realism: The Best of Both Worlds?”, in Papineau, D. (ed.), *The Philosophy of Science*, Oxford: Oxford University Press, 1996.