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New logical perspectives on physics

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This special issue is situated at the interface between Logic and the Foundations of Physics. This interface, though not as active as the logical foundations of mathematics, has long existed—with highlights such as "quantum logic", or studies of the general logical structure of physical theories. In recent years, more themes have come to the fore, and we may be witnessing a revival. The papers presented here emanate from a symposium held at the University of Utrecht in January 2008 with the aim of charting established as well as new connections between the two fields. One of the main questions discussed was whether and how modern techniques coming from logic, computer science and information theory might be combined with state-of-the-art insights in the philosophy of physics to gain a better understanding of the main foundational issues and open problems in modern physics. The success of this symposium has shown that there are several possible answers to this question. The invited papers in this issue present the reader with an overview of the main topics at play right now. A common

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feature is that all authors make essential use of logical and formal methods in physics and point out new interesting connections between the two fields.

Research in logic has made essential progress in the last decades, along many dimensions that seem relevant to the foundations of physics. One conspicuous strand concerns mathematical depth. Much traditional research in the foundations of mathematics has now begun to blend with powerful more mainstream mathematical developments in algebra, category theory and other fields, making logical techniques more widely available in mathematics and, in principle also, mathematical physics. Another noticeable trend is an ever-growing amalgam of logic and formal theories of computation and processes—perhaps the bulk of logic research as pursued today—ranging from modal logics (spatial logic, dynamic logic and temporal logic of actions) to proof-theory-inspired linear logic and other resource-sensitive logics, game logics, process algebras, coalgebraic logics, etcetera. Finally, there has also been an extension of descriptive coverage in another direction, with what has been called a "dynamic turn" toward interaction and communication between intelligent agents, bringing logic in touch with artificial intelligence, game theory, social choice theory, linguistics, cognitive science, and other disciplines modeling human behaviour in an exact manner.

The papers in this volume testify to the vitality of logic in this modern sense. For instance, modal and spatial logics can provide efficient formal tools to talk about the qualitative temporal and spatial evolution of dynamical systems. These logics can handle a large variety of interactive properties of processes and they can also be used to formalize various conceptions of space. The paper by M. Aiello, G. Bezhanishvili, I. Bloch and V. Goranko on "Logic for Physical Space" gives an overview of some of these developments by highlighting new logical perspectives on spatial structures. This reflects the larger emerging area documented in the "Handbook of Spatial Logics", edited by M. Aiello, J. van Benthem and I. Pratt-Hartmann (Springer, Dordrecht 2008).

Another current trend in logic of potential interest for physics and the philosophy of physics, is reflected in the paper by H. Andréka, J. Madarasz, I. Németi and G. Székely on "A Logic Road from Special Relativity to General Relativity". Inspired by the grand traditions of algebraic logic and classical model theory in the study of geometry, the authors present a detailed first-order analysis of the structure of both Special and general relativity theory, throwing surprising new light on their not always evident logical connections. This paper is at the same time a characteristic sample of the 'Budapest School' at the interface of logic, space-time geometry, and physics.

Another recent trend in Logic combines the use of proof theory and categorical logic with insights from the foundations of physics, as pursued in the Oxford projects of S. Abramsky and B. Coecke. The paper of B. Coecke and R.W. Spekkens on "Picturing Classical and Quantum Bayesian Inference" takes this categorical line of work one step further into the direction of a graphical representation of Bayesian inference and quantum causal relations. Another topic in this line of research, is the paper by S. Abramsky on "Big Toy Models" in which the author shows how Chu spaces can be used to represent physical systems including both classical and quantum systems.

A next trend of interest relates to intuitionistic logic and Heyting algebra, i.e., the constructive foundations of mathematics, now brought to bear on the foundations of quantum physics. The paper by C. Heunen, N.P. Landsman and B. Spitters on

"Bohrification of Operator Algebras and Quantum Logic" shows how an intuitionistic approach can shed new light on the difficulties and problems of traditional quantum logic. While traditional quantum logic has its merits, it also confronts us with deep questions that touch upon the roots of logic itself. In particular the original work of Birkhoff and von Neumann has left both philosophers and logicians wondering whether empirical theories like quantum physics can really provide principled weakening of our classical logical principles.

While the preceding paper opts for the intuitionistic approach of weakening classical logic, the paper "The Dynamic Turn in Quantum Logic" by A. Baltag and S. Smets connects traditional quantum logic with the above-mentioned dynamic turn in logic. It shows how the non-classical character of quantum logic can also be diagnosed quite differently, as the result of bringing dynamic actions of measurement on suitable quantum information systems explicitly into the logic. The result is a classical propositional logic with explicit operators for quantum measurement actions by observing agents, creating one more interface between logic, physics and computation.

Finally, the latter direction of work ties in nicely with the survey paper of J. van Benthem on "The Logic of Empirical Theories Revisited". The author first looks at the interface of logic and philosophy of science as it has functioned over the last century, and recalls some of its main trends. He then argues that bringing in agency and informational action explicitly into logical systems leads to an overhaul of formal models in the philosophy of science, bringing it much closer to the actual dynamics of observation, communication, and other activities that make up scientific inquiry.

All logical methods in this volume reach beyond traditional styles of formalizing physical theories. It is our hope that by promoting work in this direction, physicists, philosophers of physics and logicians can come closer together, and find that they have much more common ground than is often supposed. But we do not just see this as a one-way street of importing ideas. While new logical methods may be of relevance to physics, we are also well aware that physical models of information flow and even social behaviour may come to form a natural companion to existing logical and computational ones.

These are just our editorial views: now the authors will take the stage, and we are grateful for what they have provided so generously in the following pages. We also take this opportunity to thank all participants of the 2008 Symposium on Logic and Physics held at Utrecht University. Special thanks go to our fellow members of the organizing committee : Dennis Dieks, Anne Kox, and Albert Visser. Finally, we are happy to mention the sponsors who made this Symposium possible: The Evert Willem Beth Stichting, The Heyting Stichting, and the Disciplinegroep Theoretische Filosofie at the University of Utrecht.