# SPATIOTEMPORAL HISTORIES: THEORY AND APPLICATIONS
# DESCRIPTION FOR THE GENERAL PUBLIC

It is 8 pm as I am typing these words at home in Kraków, and the last train to Warsaw is due to leave in thirty minutes from Kraków main station. Given the location of my flat in Kraków, and this particular moment in time, it is still possible for me to take this train and see my older daughter in Warsaw tonight. In twenty minutes or so, this possibility of seeing my daughter tonight will be gone. But for my wife, who is now in a remote neighborhood of Kraków, it is already impossible to see our daughter tonight. After finishing this sentence, I am going to take off and run to the station… And yes, I made it. I have just talked to my daughter. Seeing her tonight turned from a future possibility to an actuality.

This little story describes what you are already acquainted with, and which philosophers call *real possibilities*. Real possibilities crucially depend on space and time, and they are dynamic, i.e., they change systematically with the passage of time. Beware that this might turn out to be an intricate issue, since the space and time we refer to need not coincide with our common sense notions, given what current physics tells us. Despite our intuitive familiarity with real possibilities, they have been little discussed in analytic philosophy, which uses formal methods (of logic or mathematics) to analyze phenomena. An exception is A. Prior's program of analyzing tense and modality by formal methods, from which the present project takes its lead. The dominant view, harking back to David Hume, and championed by positivists of various strands, tends to explain possibilities away: on such accounts possibilities are supposed to be linguistic phenomena, subjective states, or parts of our conceptual framework rather than a feature of the objective spatiotemporal world.

The best rigorous framework that explains how to coherently think and talk about real possibilities as occurring in a spatiotemporal world is given by the axiomatic theory of branching space-times (BST), put forward by Belnap (1992). That theory combines resources of modal logic and (rudimentary) relativistic space-times. In essence, a BST model consists of the set of possible spatiotemporal events, ordered by a partial ordering relation that is interpreted as "… can really occur after …". From the set of possible events, some particular subsets are formally delineated and interpreted as possible spatiotemporal histories. Additional defined notions provide the building blocks of a theory of causation, and of an account of objective probabilities.

The task of further elaborating the BST theory and applying it to problems of general metaphysics (the analysis of causation, probabilities, or a relativistically adequate concept of the present) and of philosophy of science was taken up by Thomas Müller and Tomasz Placek in the late 1990s. The three of us, Belnap, Müller and Placek, have written a few dozen papers on this theory and its applications. Despite this sizable output, however, there is no presentation of the BST theory in book form. Moreover, current models of BST have a certain feature (the existence of maximal elements in the overlap of histories) that does not square well with mathematical structures (i.e., differential manifolds) that current physics uses to represent space-times. This state of affairs, i.e., the need for new axiomatic foundations of BST and the lack of a book-length exposition of BST, lies behind our (i.e., Belnap, Müller and Placek's) decision to jointly develop a new BST theory, together with its applications, and to present the results as a book.

Our research naturally splits into two parts. In the first part we work out a comprehensive exposition of the core theory of branching space-times, including detailed proofs. After providing some informal motivation, the basic metaphysical notions of possible histories, events and their possible outcomes are defined. We put forward a new axiomatic foundation for BST, which permits one to interpret BST models as generalized (that is, non-Hausdorff) manifolds, and which alleviates, we believe, the tension between general relativity and BST. We establish some useful general facts about histories, events, and possible outcomes of events. We elaborate on the significant concept of transitions, defined as pairs of ordered events, and use them as the building blocks of a theory of causation as real difference making. On this theory, proposed in the original BST framework by Belnap (2005b), the relata of the causal relations are transitions; what causes a given transition is a set of elementary transitions, each of which keeps possible (rather than necessitates) the transition in question. Transitions are also heavily used in an account of probability (developed, in the original BST theory, by Müller (2005) and Weiner and Belnap (2006)): the base set of spatiotemporal probability spaces is provided by particular sets of transitions. Thanks to the link between transitions and causes, the resulting notion of probability is readily interpreted as graded real possibility, that is, objective single case probability (propensity). The second part of our research consists of applications of branching space-times in metaphysics and in the philosophy of physics. Our focus is on the use of BST to represent pertinent forms of indeterminism in each area. The applications concern (1) the challenge of constructing a relativistically viable concept of the present, (2) the representation of non-local quantum correlations, and (3) the discussion of determinism or indeterminism of general relativity theory.

For bibliographical references, please see the Bibliography of Full Description of the project.