Foreword

This monograph is dedicated to a novel approach for uniform modelling of timed and hybrid systems. Heinrich Rust presents a time model which allows for both the description of discrete time steps and continuous processes with a dense real-number time model. The proposed time model is well suited to express synchronicity of events in a real-number time model as well as strict causality by using uniform discrete time steps. Thus it integrates and reconciles two views of time that are commonly used separately in different application domains. In many discrete systems time is modelled by discrete steps of uniform length, in continuous systems time is seen as a dense flow. The main idea to integrate these different views is a discretization of the dense real-number time structure by using constant infinitesimal time steps within each real-number point in time. The underlying mathematical structure of this time model is based on concepts of Non-standard Analysis as proposed by Abraham Robinson in the 1950s. The discrete modelling, i.e., the description of sequential discrete algorithms at different abstraction levels, is done with Abstract State Machines along the formalisms developed by Yuri Gurevich and temporal logic. These ingredients produce a rich formal basis for describing a large variety of systems with quantitative linear time properties, by seamless integration, refinement and embedding of continuous and discrete models into one uniform semantic framework called "Non-standard Timed Abstract State Machines" (NTASM).

On this theoretically well-founded and elegant basis Heinrich Rust discusses typical problems of time models like "zero time" and "Zeno behaviour," interleaving semantics, time bounds and composition of open systems. The semantic description of two variants of quantitative timed Petri nets, timed automata and hybrid automata with NTASM models shows the generality of the NTASM approach.

This book is an important contribution to the research area of time modelling formalisms. The presentation is well-balanced between theoretical elaboration and a critical discussion of the applicability of the theoretical results by means of appropriate case studies. The new temporal semantics proposed and discussed here can help theoreticians as well as practitioners in gaining better understanding of time models and in building better notations, models and tools for the formal treatment of systems where time matters.

Cottbus, January 2005 Claus Lewerentz

Preface

Time is a fascinating subject. It seems to be quite difficult to come to grips with it. Saint Augustine, in Chapter 14 of Book 11 of the Confessions, said it in this classical way:

> *What, then, is time? If no one asks me, I know what it is. If I wish to explain it to him who asks me, I do not know.*

Making our intuitive understanding of a rich phenomenon explicit, we risk being refuted, by others and by ourselves; and time is an especially rich and irreducible phenomenon. If the subject of time is dealt with in a theological or philosophical context (as Augustine did), this is especially clear, since here time is intimately connected to the concept of existence.

But also in a technical discipline like computer science, time is no simple subject. Here, the question is not what time **is**, but how it should be **modelled** in different situations. Unfortunately, the difference between these questions might seem larger than it turns out to be when we consider specific situations. A model of some phenomenon should abstract from features which are not important in the class of situations considered, while important features should be retained in the model. Thus, dealing with the question of how time should be modelled, we also have to deal with the question of what **are** the important features of time in a class of situations.

A model does not only have to be adequate for the modelled phenomena. If it is to be usable by humans it should also be adequate for their cognitive capabilities. This is sometimes used to justify striving for models that are as simple as possible (while sufficient adequacy with respect to the phenomena is retained). But cognitive simplicity is not an objective trait of a model; with familiarization, a formerly complex model might become simple for somebody working with it. If a model for some phenomenon exists which is very rich in the sense that many other models can be described as special cases of it, then using this model might sometimes be even simpler than using the special cases, and the rich model can serve as an integration platform for ideas which first were used with the more special models. In this way, some unification of concepts might be possible.

This book presents work in which a fairly novel model of quantitative time is tried out, one we hope is both general enough and simple enough to be used as an integration platform for ideas springing from different models of quantitative time. The model of time is discrete, which means that for each moment there is a well-defined next moment. The model of time is uniform, i.e., the distance between two moments is always the same; and nevertheless it is dense in the real numbers as they are used in classical mathematics, i.e., the resolution induced by the step width is so fine that any real numbered point in (classical) time is approximated by a time point of the model with vanishing error.

After you have read how this model of time is made explicit in this book, you will undoubtedly also see some drawbacks in the approach (several of them are listed in the summary at the end of the book). If you understand this list of drawbacks as a refutation of the approach proposed, then in your eyes I have fallen prey to the problem described above in the citation of Augustine. Let me confess that I myself am not yet completely sure how to interpret the drawbacks. This needs some more investigation.

Credits

A considerable number of people helped during the work which resulted in this book. Claus Lewerentz supported the work from the beginning. My colleagues, especially Dirk Beyer, discussed features of timed systems with me and helped with the presentation, as did in some phases of the work Andreas Prinz and Angelo Gargantini. Egon Börger and Dino Mandrioli gave hints regarding the exposition of ideas and the need to discuss some specific features of the formalism in more depth. The editors at Springer worked hard at correcting my English. And finally, my wife, Korinna Hiersche, made sure that I had time for this work during a parental leave, as did my son Alexander by his arrival.

Cottbus, December 2004 Heinrich Rust