

Preface

Time and Petri nets – do they not contradict each other? While time determines the occurrences of events in a system, classic Petri nets consider their causal relationships and represent events as a concurrent system. At first, these two appear to be at odds with each other, but taking a closer look at how time and causality are intertwined, one realizes that time actually enriches Petri nets. There are many possible ways in which time and Petri nets interact, this book takes a deeper look at three time-dependent Petri nets: Time Petri nets, Timed Petri nets, and Petri nets with time-windows.

The aim of this book is to introduce different algorithms that can be used to analyze these three time-dependent Petri nets, as well as the principal methods for analyzing nets in general. To give the reader a general understanding of Petri nets and their origins, we will first take a look at classic Petri nets and their fundamental properties. Once the basis has been laid, we will take a dive into time-dependent Petri nets, which are an extension of classic Petri nets.

There are many different possibilities to associate time to classic Petri nets. For the three time-dependent Petri nets this book focuses on, time is associated to transitions or to places. For the first nets that we will take a look at, Time Petri nets, enabled transitions may fire only during specified time intervals. The transitions must fire the latest at the end of their intervals if they are still enabled then. At any given moment only one transition may fire. This firing does not take time. For the second class of nets, Timed Petri nets, a maximal set of just-enabled transitions fires, and the firing of each transition takes a specific amount of time. The third class of nets, Petri nets with time-windows, portrays time as a minimum and maximum retention for tokens on places. In these nets tokens can be used for firing only during their minimum and maximum retention. At the end of the maximum retention

time for a token its time is reset to zero if it was not used for firing. The next period of its retention time on this place then restarts. This repetition can continue indefinitely.

The pivotal contribution of this book is the introduction of algorithms that allow the analysis of the different kinds of time-dependent Petri nets. For each class of time-dependent nets, we will consider different algorithms that have specifically been invented for the analysis. For Time Petri nets, we provide an algorithm which proves the behavioral equivalence of a net where time is designed once with real and once with natural numbers. One can also say that the *dense semantics* of Time Petri nets can be replaced with *discrete semantics*. The added value of this approach is that at this point we can reduce the state space of a Time Petri net and consider its integer-states exclusively. The result then allows for a qualitative and quantitative analysis.

As a new approach for Timed Petri nets, we introduce two *time-dependent state equations*. These provide a sufficient condition for the non-reachability of states. We also define a local transformation for these nets into Time Petri nets. Eventually we show possible variations of them.

Last but not least, we prove that Petri nets with time-windows have the ability to realize every transition sequence fired in the net omitting time restrictions. Despite the first experience that time has no influence on the behavior of such nets, we verify that the time can change the liveness behavior of Petri nets with time-windows.

Finally, we choose these three classes of time-dependent Petri nets to show that time alone does not change the power of a Petri net. In fact, time can or cannot be used to force firing. For Time Petri nets and Timed Petri nets we can say that they are Turing-powerful, and thus more powerful than classic Petri nets. The reason for this is that there is a compulsion to fire at some point in time. For Time Petri nets this is at the latest point of an interval, and for Timed Petri nets this is immediately after enabling. In contrast to these two nets, Petri nets with time-windows have no compulsion to fire. Their *expressiveness power* is less than that of Turing-machines.

This book is based on a script I have been using for my advanced lecture on *Time and Petri nets*. To read and understand it, you do not need advanced mathematical knowledge, except for the section on *quantitative evaluation*

of *Time Petri Nets*, where some insight into operational research and graph theory will be useful.

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