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Industrial applications of the PetriDotNet modelling and analysis tool

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ARTICLE INFO

Article history:

Received 30 December 2016

Received in revised form 5 July 2017

Accepted 11 September 2017

Available online xxxx

Keywords:

Petri nets

Modelling

Simulation

Model checking

Stochastic analysis

ABSTRACT

Since their invention, Petri nets have provided modelling and analysis methods to support the design of correct, reliable and robust systems. This motivated our work to develop PetriDotNet, a Petri net editor and analysis tool. In this paper we overview the supported modelling formalisms and the analysis methods included in PetriDotNet. Next, we present eight different industrial case studies, demonstrating the wide variety of scenarios where Petri nets and PetriDotNet can help the design, development and analysis of industrial systems. Our original goal with PetriDotNet was to provide an educational tool to our students, however our efforts led to a framework being able to serve both academic and industrial needs.

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1. Introduction

In the past decades, modelling and model-based analysis have taken a prominent role in the design of computer-based systems. The qualitative and quantitative design-time analysis of models provided early feedback for the developers, allowing them to check the functional correctness of the design, estimate extra-functional characteristics like performance or dependability, and evaluate design alternatives.

In this context, one of the most popular modelling formalisms was Petri nets, since its variants provided simple but powerful representations of the various aspects of the systems under design. The success of Petri nets was due to their straightforward syntax (with intuitive graphical representation) and semantics addressing especially concurrency and causality of events, extended later with the possibility to model (among others) data processing, timing and probabilistic behaviour. The analysis possibilities of basic Petri net models focused on checking the state space of the modelled system, including state reachability, invariants, general safety and liveness properties, as well as temporal logic model checking. Stochastic extensions allowed the evaluation of state probabilities and reward measures representing service quality (e.g. performance and dependability).

As it turned out, Petri nets with an appropriate editor and powerful analysis methods provide tools for the engineers to model, study and analyse various problems in system and software development. The modelling and analysis of event-driven

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concurrent systems is well-supported by P/T nets and related analysis techniques: state reachability and temporal logic model checking provide useful means to verify the logical correctness of communicating systems such as control logics or communication protocols. Data processing can be efficiently modelled by coloured Petri nets, this way supporting the design of distributed algorithms and workflows. Invariant analysis, deadlock checking and model checking methods can be used to ensure the correctness of data-dependent behaviour. Stochastic modelling and analysis of state probabilities yield modelling and analysis of service quality properties of critical systems such as reliability, performance or availability.

In this paper we discuss PetriDotNet, a Petri net editor and analysis tool for P/T, coloured and stochastic Petri nets. Besides simulation and simple structural and dynamic analysis methods, the work of the last ten years resulted in many powerful analysis features. In our previous paper [1], we have focused on the educational use of PetriDotNet. Here we demonstrate that Petri nets and PetriDotNet can aid the design and development of industrial systems with its modelling and analysis features.

For this purpose, we define the Petri net variants supported by our tool and we give a short introduction to the main discrete and stochastic analysis features. Then, we showcase a wide variety of industrial use cases from different domains, including the verification of the safety logic of a nuclear power plant, analysis of power consumption of sensor nets, test input generation for communicating robots, analysis of public transport networks, studying railway interlocking systems, hazard rate calculation of a fault-tolerant automotive control system, analysis of an IaaS cloud, and an extensive benchmark on various models. In some applications the modelling features were exploited and in other cases the analysis features were more dominant; some cases demonstrate the usability of P/T nets, some others underline the advantages of coloured or stochastic net representations; some cases were done by the PetriDotNet development team and other applications by independent industrial practitioners.

This paper shows evidence of PetriDotNet being a convenient tool to design Petri net based analysis models and to evaluate them by performing simulation, discrete and stochastic analysis. A wide range of analysis capabilities is supported by PetriDotNet and case studies showed that we could model and verify systems which were not possible to be analysed before. The case studies also emphasise that the tool is competitive with other frameworks in this field.

Structure of the paper. The structure of this paper is the following. Section 2 introduces the modelling and requirement formalisation languages used in the article: different variants of Petri nets and temporal logics. Section 3 focuses on the current functionality of PetriDotNet and describes the discrete and stochastic analysis algorithms included in our tool. Next, we present industrial use cases in Section 4. The related work on industrial usage of Petri nets is presented in Section 5. Finally, Section 6 summarises and concludes the paper.

This article is an extended version of our previous conference paper [1]. The major novel contributions are the extensive description and discussion of analysis algorithms included in PetriDotNet (in Section 3), the detailed description of industrial cases where PetriDotNet was proven to be applicable and useful (Section 4) and the related work on the industrial usage of Petri nets (Section 5).

2. Background

This section introduces the modelling and requirement formalisation languages that are supported by PetriDotNet and are used in the rest of this paper. Section 2.1 describes three variants of Petri nets: P/T nets, coloured Petri nets and stochastic Petri nets. Section 2.2 presents languages for describing temporal requirements, and Section 2.3 is dedicated to quantitative requirements. Although the rest of the paper is more informal and the definitions are less frequently used, we still include them in this section to precisely describe the semantics of the supported modelling and requirement formalisms.

2.1. Variants of Petri nets

This section presents the variants of Petri nets that are supported by PetriDotNet, namely Petri nets (Section 2.1.1), coloured Petri nets (Section 2.1.2) and stochastic Petri nets (Section 2.1.3).

2.1.1. Petri nets

Petri nets are graphical models for describing concurrent, non-deterministic and asynchronous systems, providing both structural and dynamic analysis [2]. Formally, a Petri net (also referred to as Place/Transition net or P/T net²) is a tuple $PN = (P, T, E, W, m_0)$, where

- P is the finite set of *places*,
- T is the finite set of *transitions* with $P \cap T = \emptyset$,
- $E \subseteq (P \times T) \cup (T \times P)$ is the finite set of *arcs*,
- $W: E \mapsto \mathbb{Z}^+$ is the *weight function* assigning weights $w^-(p, t)$ to edges $(p, t) \in E$ and $w^+(p, t)$ to edges $(t, p) \in E$, and
- m_0 is the *initial marking*.

² The name “Place/Transition net” is used in the following to emphasise that the Petri net is neither coloured, nor stochastic.

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