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Petri Nets Research at BTU in Cottbus, Germany

We present the Petri net related research activities running at the Chair for Data Structures & Software Dependability within the Computer Science Institute at the Brandenburg University of Technology Cottbus-Senftenberg, Germany. The group currently includes the staff members Martin Schwarick and Christian Rohr, and is headed by Monika Heiner.

Overview

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Curriculum Vitae

Monika Heiner received her Diploma degree and Ph.D. in Computing Science from the University of Technology in Dresden, Germany. Since 1994 she holds a professorship for *Data Structures & Software Dependability* at the Brandenburg University of Technology in Cottbus, Germany, and since 2011 she is Visiting Professor within the Department of Computer Science, Brunel University London, UK.

She has been visiting research fellow at the International Computer Science Institute (ICSI) in Berkeley, California (1992), Boston University, Metro-

politan College, MA (1999/2000), University of Costa Rica, San José (2003), INRIA Rocquencourt, France (2007), Universidad de Zaragoza, Spain (2010), Brunel University London, UK (2011), and Laboratoire Spécification et Vérification (LSV/ENS), Cachan/Paris, France (2013).

She fell in love with the Petri net formalism while looking for a Ph.D. subject, shifting her application focus from hardware & software to natural systems in the late nineties. Over the last 20 years her group at Cottbus has developed a sophisticated toolkit for BioModel Engineering, which has been used in numerous case studies. She has co-authored 70 peer reviewed articles and 9 book chapters.

Her academic service includes 13 editorships of conference proceedings and special focus issues. She is a Steering Committee member of the International Conference on Computational Methods in Systems Biology (CMSB), and on the Editorial board, Broader Perspective of the Journal Natural Computing. Since 2010, she is organising and co-chairing the yearly International Workshop on Biological Processes & Petri Nets (BioPPN) as satellite event of the PETRI NETS Conference series. She has served on numerous programme committees, among them CMSB, PETRI NETS, and SIMULTECH (International Conference on Simulation and Modeling Methodologies, Technologies), and reviews journal articles on a regular basis.

Teaching

It's hard to resist the seductive power of Petri nets, and after a while everything is seen through Petri net glasses. Thus, our courses are famous for having all some Petri net material included.

Introduction into Concurrency teaches basic techniques of model-based construction of concurrent systems, with deploying Petri nets as modelling language and Java as implementation language. The course introduces terminology and basic concepts of Petri net theory, and applies Petri nets to gain deeper understanding of the principles underlying concurrent systems and concurrent programming concepts, such as semaphores, monitors (Concurrent Pascal), rendezvous concepts (Ada), and channel communication (OCCAM).

Modelling and Analysis of Concurrent Systems builds on the introductory course and deepens the understanding of Petri nets by devoting much time to the comparison of interleaving and partial order semantics. It covers most of the advanced Petri net analysis techniques, including explicit and symbolic model checking.

Software Dependability teaches concepts and methods to improve the dependability of software-based systems, including defensive and di-

verse programming concepts supporting various aspects of fault avoidance and fault tolerance. Model-based software development and verification by means of Petri nets is a cornerstone of fault avoidance, while Petri nets are deployed as well to highlight the basic principles of fault-tolerant software structures.

Software Testing covers systematic testing strategies of software-based systems, by stressing the strength of testing in comparison with verification techniques. Petri net knowledge is asked for the testing strategy by means of cause/effect graphs, which are evaluated by Petri net T-invariants, and for all testing strategies aiming at thorough and systematic testing of concurrent software.

Research

Most of our research deals with Petri nets and related modelling and analysis techniques. Previously we were much concerned with Software Dependability Engineering with focus on reactive systems, see [HDS99] for a popular case study.

Since the late nineties, the main application area is **BioModel Engineering** which we understand as the science of engineering – in other words systematically constructing, maintaining and deploying – computational models of biochemical processes in an efficient, sustainable and trustworthy manner. Ideally, the models have high explanatory and predictive power.

General objectives include

Bridging the gap between qualitative (time-free) and quantitative (timed) approaches to model and analyse natural as well as technical systems.

A distinct characteristic of systems biology is that one and the same model (in terms of its structure, kinetics, and initial conditions) can and often has to be interpreted in different modelling paradigms. These may comprise the qualitative, stochastic, deterministic and hybrid setting and are supported by corresponding Petri net classes. Changing the paradigm comes sometimes with counter-intuitive effects in the system behaviour, which are – so far – not in all cases well understood.

Managing diversity by collecting and user-friendly preparation of formal methods, and by the provision of tools for the practically working computer scientist or biologist/medical researcher interested in computational modelling.

More specifically, our research aims

To pioneer reproducible computational research by the development of reliable and trustworthy modelling and analysis techniques and related tools with special focus on systems and synthetic biology;

To foster the application of computational methods in biochemical and medical applications. The long-term goal is to apply this research for personalised medicine.

See [HG11] for a detailed treatment of how Petri nets might enhance a biologist's toolkit for systems and synthetic biology (state of the art in 2011). On-going research deals with modular modelling [BDR+13], multiscaleness and spatial aspects [HG13], developmental processes, and parallel simulation.

Tools

A crucial point of BioModel engineering is reproducibility, and reproducible computational research in systems biology requires reliable software tools with long-term availability. Reliability of non-trivial software grows over the years by intensive use and careful maintenance. Most of our tools are implemented in C++ to gain favourable performance measures.

Snoopy [RMH10, HHL+12] is a platform supporting the construction and animation and/or simulation of various types of Petri nets, including standard Petri nets and their extension by special arcs as well as stochastic, continuous and hybrid Petri nets, which each exist as uncoloured and coloured nets. Snoopy supports several data exchange formats, among them SBML import/export.

Snoopy is under development since about 2000 with many contributions from former diploma and Ph.D. students. Since 2008, it is maintained by Christian Rohr, with support by Mostafa Herajy (simulation) and Fei Liu (coloured net classes).

S^4 **- Snoopy simulation steering server** [HH14] is a stand-alone tool supporting interactive and remote simulation of stochastic, continuous and hybrid Petri nets with Snoopy as client.

S^4 has been developed and is maintained by Mostafa Herajy.

Charlie [Sch06, Fra09] builds on the experience gained over about 20 years while using INA (Integrated Net Analyser) previously developed at Humboldt University Berlin by Peter Starke. Charlie applies standard analysis techniques of Petri net theory to determine structural and behavioural properties of Petri nets, complemented by explicit CTL and LTL model checking.

Charlie's primary focus is teaching of Petri net theory. It is a Java application and has been developed by Martin Schwarick, with substantial contribution by Andreas Franzke, Ansgar Fischer, and Jan Wegener.

Marcie [HST09,HRS13] started as a symbolic analysis tool for (qualitative) Petri nets, supporting standard properties and CTL model checking. It has then been further developed for symbolic on-the-fly CSL model checking of stochastic Petri nets, recently extended by rewards. The efficiency of the symbolic engines is gained by Interval Decision Diagrams. Exact analyses are complemented by approximative PLTLc model checking applying Fast Adaptive Uniformization (FAU) and distributed stochastic simulation (Gillespie, Tau leaping).

Marcie took part in the Model Checking Contest, held at Petri Nets 2013, where it scored silver or gold in 11 out of 12 examinations in the surprise model category (unknown models), see [KLB+13] for the detailed report.

Marcie's symbolic engines have been developed by Alex Tovchigrechko and Martin Schwarick, the engines for approximative model checking by Christian Rohr.

Patty [Sch08] permits the animation of (extended) Petri nets (in Snoopy format) within a web browser, building on SVG and JavaScript technologies.

Patty has been developed by Krispin Schulz and Marcel Schwarze.

All Petri net tools are publicly available at `http://www-dssz.informatik.tu-cottbus.de`, and are free of charge for academic use.

Our tools play a crucial role in teaching Petri nets, they are applied in all our courses. Moreover, they are in worldwide use for technical and biological applications; our website hosts a bibliography of related research articles and Ph.D. theses.

Main Collaborators

No interdisciplinary research without collaborators; close and long-term collaborations are running with:

- Professor David Gilbert
  Brunel University London, Department of Computer Science, and Centre for Systems and Synthetic Biology,
  `http://people.brunel.ac.uk/~csstdrg/`

- Professor Wolfgang Marwan
  Otto von Guericke University, Regulatory Biology, and Magdeburg

Centre for Systems Biology (MaCS),
`http://www.regulationsbiologie.de`

Further close collaborations are undertaken with former Ph.D. students, including:

- Dr. rer. nat. Fei Liu, Associate Professor
  Control and simulation Center, Harbin Institute of Technology
  `http://homepage.hit.edu.cn/pages/liufei`
- Dr. rer. nat. Mostafa Herajy, Assistant Professor
  Mathematics and Computer Science Department, Faculty of Science, Port Said University, Egypt,
  `http://psu.edu.eg/staff/mostafaherajy/index.php`

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