informatics / *mathematics*

Inria

Activity Report 2013

Team TRIO

Real-time and interoperability

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<div align="center">**Team TRIO**</div>

Keywords: Embedded Systems, Real-Time, Safety, Energy Consumption, Scheduling, WCET Estimation

Creation of the Project-Team: 2002 January 01*, updated into Team:* 2012 January 01, end of the Team: 2013 August 31.

1. Members

Research Scientists

Liliana Cucu-Grosjean [Team leader, Inria, Researcher, until August 2013]
Olivier Zendra [Inria, Researcher, until August 2013]

Faculty Member

Jean-Pierre Thomesse [University of Lorraine Nancy, Professor]

External Collaborators

Pierre Caserta [University of Lorraine, Doctor, until February 2013]
Nicolas Navet [Professor, University of Luxembourg]

Engineers

Adriana Gogonel [Inria, until May 2013]
Codé Lo [Inria, until July 2013]
Cristian Maxim [Inria, until August 2013]

PhD Student

Dorin Maxim [Inria, CORDI-S, since October 2010]

Visiting Scientist

Robert Davis [University of York, Researcher, until May 2013]

Administrative Assistants

Chantal Chretien [CNRS]
Sophie Drouot [Inria]
Marie-Françoise Loubressac [Inria, until January 2013]

Others

Romarik Jodin [Inria, Intern, from June 2013 until September 2013]
Robin Bressan [Inria, Intern, from April 2013 until September 2013]
Anis Koubaa [Ecole des Mines de Nancy, Intern, from October 2013]

2. Overall Objectives

2.1. Objectives of the team

The goal of the TRIO team is to provide a set of techniques and methods that can be applied to design, validate and dimension real time distributed applications. In order to tackle this problem as a whole, our work is structured along two complementary points of view:

- specification of real-time on-line mechanisms (protocols, schedulers, middleware) offering services to the application with a quality of service that ensures the satisfaction of real time constraints; this includes fault detection, fault recovery and fault tolerance,

- modeling, analysis and evaluation of real time distributed systems for the verification of temporal properties and the optimisation of distributed deployment.

Furthermore, we continue to study the modeling process of real time distributed applications that allows the description of both functional and non-functional aspects of these applications and therefore a formal use of these models for quantitative evaluation and optimal scaling.

The problems to solve are mainly due to three particularities of the targeted applications:

- They are discrete event systems with temporal characteristics (temporal performances of hardware support, temporal properties); this increases the complexity of their modeling and of their analysis. Hence a part of our research objectives is to master this complexity while achieving a satisfactory trade-off between the accuracy of a model and its ability to be analyzed.
- A second aspect is the environment of these systems that can be the cause of perturbations. We need to take into account the impact of an uncertain environment (for example, the impact of electro-magnetic perturbations on a hardware support) on the required properties. Therefore we have to develop probabilistic approaches.
- Finally, the main characteristic of our work is based on the fact that we consider the performances of the hardware support. Consequently, the time that we manipulate is a physical (continuous) time and the studied systems are event driven timed systems.

These above mentioned main directions contribute to cover the full spectrum from formal modeling and evaluation of real time distributed systems up to their use in industrial problems.

2.2. Highlights of the Year

This is the last activity report of TRIO team, as the team ends in 2013. TRIO has been, originally, created in 2002 under the guidance of Françoise Simonot-Lion. In 2010, when Françoise became director of Laboratoire Lorrain de Recherche en Informatique et ses Applications (LORIA), Nicolas Navet became the leader of the team. In 2012, when Nicolas Navet became Professor at University of Luxembourg, Liliana Cucu-Grosjean became the last leader of TRIO team. The team ends on an excellent Inria evaluation in 2012 that underlines the important contribution of its members within their scientific communities. Following the natural life process of an Inria team, the end of TRIO indicates the evolution of its members to new exciting research problems.

Liliana Cucu-Grosjean gave the keynote talk of the 21st International Conference on Real-Time Networks and Systems. Her talk concerned the probabilistic real-time systems.

Dorin Maxim and Liliana Cucu-Grosjean published a paper entitled "Response Time Analysis for Fixed-Priority Tasks with Multiple Probabilistic Parameters" at the IEEE Real-Time Systems Symposium (RTSS), the flag conference on real-time systems.

The FP7 STREP PROARTIS has been successfully completed in July 2013. TRIO was leader of the work package on the probabilistic approaches and tools within this project.

3. Research Program

3.1. Foundation

In order to check for the timing behavior and the reliability of distributed systems, TRIO team developed several techniques based on deterministic approaches ; in particular, we apply and extend analytical evaluation of worst case response times and when necessary, e.g. for large-scale communication systems as Internet based applications, we use techniques based on network calculus.

The arrival of complex hardware responding to the increasing demand for computing power in next generation systems exacerbates the limitations of the current worst-case real-time reasoning. Our solution to overcome these limitations is based on the fact that worst-case situations may have a extremely low probability of appearance within one hour of functioning (10^{-45} [7]), compared to the certification requirements for instance (10^{-9} for the highest level of certification in avionics). Thus we model and analyze the real-time systems using probabilistic models and we propose results that are fundamental for the probabilistic worst-case reasoning over a given time window.

In the design of discrete event systems with hard real time constraints, the scheduling of the system's activities is of crucial importance. This means that we have to devise scheduling policies that ensure the respect of time constraints on line and / or optimize the behavior of the system according to some other application-dependent performance criteria.

In order to foster the best quality for programs, their understanding has to be automated, or at made significantly easier. Thus, we focus on analyzing and modeling program code, program structure and program behavior, and presenting these pieces of information to the user (in our case, program designers and program developers). Modeling user interaction is to come as well.

In the design of embedded, autonomous systems, power and energy usage is of paramount importance. We thus strive to model energy usage, based on actual hardware, and derive context-aware optimizations to decrease peak power and overall energy usage.

4. Application Domains

4.1. TRIO application domains

Three main application domains can be underlined.

- In-vehicle embedded systems. The work developed in TRIO is oriented towards transportation systems (cars, airplanes, trains etc.). They mainly cover two points. The first one is the specification of what must be modeled in such a system and how to reach a good accuracy of a model. The second point concerns the verification of dependability properties and temporal properties required by these applications.

- Compilation, memory management and low-power issues for real time embedded systems. It becomes mandatory to design embedded systems that respect performances and reliability constraints while minimizing the energy consumption. Hence, TRIO is involved, on the one hand, in the definition of ad-hoc memory management at compilation time and on the other hand, in joint study of memory management strategies and tasks scheduling for real time critical systems.

- Code analyses and software visualization for embedded systems. Despite important advances, it is still impossible to develop and optimize automatically all the programs with all their variety, especially when deployment constraints are considered. Software design and implementation thus remain highly ad-hoc, poorly automated activities, with a human being in the loop. TRIO is thus involved in the design of better tools for software engineering focusing on helping the human developer understand and develop the system, thanks to powerful automated program analyses and advanced visualizations techniques.

5. Software and Platforms

5.1. ANR Open-PEOPLE platform

Participants: Anis Koubaa, Olivier Zendra.

The aim of Open-PEOPLE is to provide a platform for estimating and optimizing the power and energy consumption of systems. The Open-PEOPLE project formally started in April 2009.

In 2013, work in TRIO on this platform was minimal, because of the lack of development resources.

We performed software updates on the servers, ensuring the continuity of access (which is especially important since other partners of the former ANR Open-PEOPLE project still use this platform and actively develop on it). We fixed a few bugs on the platform.

In late 2013, we started working, in the context of Anis Koubaa's student project, on adding a new functionality to help develop energy combustion models, namely the automatic extraction of mathematical laws, derived from the measurements (cloud of points) coming from the experimental hardware platform.

5.2. VITRAIL

Participants: Pierre Caserta, Romarik Jodin, Olivier Zendra.

The aim of the VITRAIL operation is to provide tools for the advanced and immersive visualization of programs. Some of this work has been done with the University of Montréal, the University of Montpellier and to a lesser extent the Pareo team of Inria Nancy Grand Est.

Last years, in VITRAIL, we had developed software to instrument and trace Java programs at the bytecode level. We then had developed an analysis tool able to exploit these traces to compute relevant software metrics.

In 2013, we were able to restart developments on the VITRAIL platform.

We first explored a Linux port, toward which we progressed but were stopped by the fact we relied on Ogre3D, a library that calls some Windows specific APIs. We have identified those, and we believe that an OpenGL port would be a sensible path to OS portability.

We also ported our VITRAIL Vizualizer software to a new type of display, namely 3 interactive whiteboards placed so as to form a 3-side box.

Finally, we also successfully implemented a first prototype of interaction through a head-tracking system relying on two cameras. First experiments gave promising results.

6. New Results

6.1. Probabilistic real-time systems

Participants: Liliana Cucu-Grosjean, Adriana Gogonel, Codé Lo, Dorin Maxim and Cristian Maxim.
The arrival of complex hardware responding to the increasing demand for computing power in next generation systems exacerbates some of the limitations of static timing analysis for the estimation of the worst-case execution time (WCET) estimation. In particular, the effort of acquiring (1) detail information on the hardware to develop an accurate model of its execution latency as well as (2) knowledge of the timing behaviour of the program in the presence of varying hardware conditions, such as those dependent on the history of previously executed instructions. These problems are also known as the timing analysis walls. The probabilistic timing analysis, a novel approach to the analysis of the timing behaviour of next-generation real-time embedded systems, provides answers to timing analysis walls. In [7], [13], [11] timing analysis attacks the timing analysis walls. We have also presented experimental evidence that shows how probabilistic timing analysis reduces the extent of knowledge about the execution platform required to produce probabilistically-safe and tight WCET estimations.

Based on existing estimations of WCET or minimal inter-arrival time [16], we may propose different probabilistic schedulability analyses [6], [12].

2013 was also the year when through several invited talks [8], [10], [9], we had the opportunity to underline historical misunderstandings on probabilistic real-time systems. The most common is related to the notion of independence that is used with a wrong meaning by different papers.

7. Partnerships and Cooperations

7.1. National Initiatives

7.1.1. BGLE DEPARTS

Participants: Liliana Cucu-Grosjean, Adriana Gogonel, Codé Lo, Cristian Maxim.

The project DEPARTS started on October 1st, 2012, but for administrative reasons the kick-off meeting was only on April, 2013. This project is funded by the national funding program BGLE. TRIO team proposes solutions for probabilistic component-based models and a PhD thesis will start early 2014. Such solution allows designers to unify in the same framework probabilistic scheduling techniques and compositional guarantees that have different levels of criticality. The schedulability analysis presented in [12], [6] are the bases of our future contributions.

7.2. European Initiatives

7.2.1. FP7 Projects

7.2.1.1. PROARTIS

Type: COOPERATION

Defi: Embedded Systems Design

Instrument: Specific Targeted Research Project

Objectif: Embedded Systems Design

Duration: February 2010 - July 2013

Coordinator: Barcelona Supercomputing Center (Spain)

Inria contact: L. Cucu-Grosjean

Participants: Liliana Cucu-Grosjean, Adriana Gogonel, Codé Lo, Dorin Maxim and Cristian Maxim.

TRIO team participates to PROARTIS which is a STREP project within the FP7 call and it started on February 2010. It has six partners: Barcelona Supercomputing, University of York, University of Padova, Inria and Airbus. The overarching objective of the PROARTIS project is to facilitate a probabilistic approach to timing analysis. The PROARTIS approach concentrates on proving that pathological timing cases can only arise with negligible probability, instead of struggling to eradicate them, which is arguably not possible and could severely degrade performance. This is a major turn from previous approaches that seek analyzability by predicting with cycle accuracy the state of hardware and software through analysis.

The PROARTIS project facilitates the production of analysable CRTE systems on advanced hardware platforms with features such as memory hierarchies and multi core processors.

This project ended July 2013.

7.2.1.2. PROXIMA

Type: COOPERATION

Defi: Mixed-Criticality Systems

Instrument: Integrated Project

Objectif: Development of probabilistic approaches for mixed-criticality systems on multi-core and many-core platforms

Duration: October 2013 - September 2016

Coordinator: Barcelona Supercomputing Center (Spain)

Inria contact: Liliana Cucu-Grosjean

Participants: Liliana Cucu-Grosjean, Adriana Gogonel, Codé Lo, Dorin Maxim and Cristian Maxim.

PROXIMA project started on October 1st, 2013 with a kick-off meeting in November 2013.

The PROXIMA hypothesis is that probabilistic analysis techniques can provide efficient (tractable) and effective (tight) analysis of the temporal behaviour of complex mixed-criticality applications on novel multicore and manycore platforms. Solid research results from the FP7 STREP PROARTIS project underpin this claim. The concept is based on using probabilistic analysis techniques to derive safe and tight bounds on the temporal behaviour of applications, reflecting requirements on failure rates commensurate with their criticality. PROXIMA defines architectural paradigms that break the causal dependence in the timing behaviour of execution components at hardware and software level that can give rise to pathological cases, and reduces that risk to quantifiable small levels. Only modest changes will be needed to this end in the hardware and software components beneath the application (processing cores, interconnects, memory hierarchies and controllers, real-time operating system, middleware, compilers).

7.2.2. *Collaborations in European Programs, except FP7*

7.2.2.1. European Network of Excellence (NOE) High Performance Embedded Architectures and Compilation (HiPEAC)
Participant: Olivier Zendra.

The TRIO team is involved in the HiPEAC 3 (High Performance Embedded Architecture and Compilation) European Network of Excellence (NoE). Olivier Zendra was initiator and leader in this context of a cluster of European Researchers "Architecture-aware compiler solutions for energy issues in embedded systems" from mid-2007 to mid-2009. A STREP proposal tentatively titled "RuSH2LEAP: Runtime Software-Hardware interactions to Lower Energy And Power" was written at the beginning of 2013, mostly in the context of this network of excellence, for submission in Call ICT 2013.10, challenge 3.4 Advanced computing, embedded and control systems. The proposal passed all thresholds, but failed to be funded.

7.3. International Research Visitors

7.3.1. *Visits of International Scientists*

Rob Davis (University of York) has continued to visit TRIO within the UK Seedcorn Grant that covers his visits in Nancy. This collaboration allowed to successfully apply for a FP7 IP project as well as an Inria International Chair that will start in 2014 within AOSTE (team that Liliana Cucu-Grosjean, Adriana Gogonel, Codé Lo and Cristian Maxim had joined before the end of 2013).

8. Dissemination

8.1. Scientific Animation

- Liliana Cucu-Grosjean has been the Delegate of International Relations for the Inria Nancy-Grand Est center until September 1st 2013.
- Liliana Cucu-Grosjean is an elected member of Inria Evaluation Commission (CE).
- Liliana Cucu-Grosjean is head of the Inria Committee on Equal Opportunities
- Olivier Zendra is head of the Documentation Committee of Inria Nancy Grand Est (Commission IST); member of the Health, Safety and Work Environment of Inria and of Inria Nancy Grand Est - LORIA Committees (CNHSCT and CLHSCT); member of the Inria Committee on Prevention of Psycho-social Risks and Quality of Life at Work (PRPS-QVT); member of the Permanent Education Committee of Inria Nancy Grand Est - LORIA; member of the new Sustainable Development Local and National Committees; member of the Inria Nancy Grand Est - LORIA Committee for the selection of hardware configurations; member of the Inria Committee on Equal Opportunities
- Liliana Cucu-Grosjean was member of the selection committee at University of Lorraine (position 27MCF0387), University of Toulouse (position 61MCF0789) and Inria Nancy-Grand Est (CR2 contest)

- Olivier Zendra is CIR expert for the Ministry of Research for the scientific evaluation of research in companies.
- Liliana Cucu-Grosjean is an ANRT expert for evaluating CIFRE applications.
- Olivier Zendra was an expert for evaluating COFECUB applications in 2013.
- Olivier Zendra is founder and steering committee member of the ICOOOLPS (International Workshop on Implementation, Compilation, Optimization of Object-Oriented Languages, Programs and Systems) workshop, usually joint to ECOOP.
- Liliana Cucu-Grosjean is steering committee member of RTSOPS (joint workshop of ECRTS) and WMC (joint workshop of RTSS).
- Liliana Cucu-Grosjean was co-chair of RTSOPS (ECRTS 2012) and WMC (RTSS 2013) as well as co-editor of the respective proceedings.
- Liliana Cucu-Grosjean was program committee member of IEEE RTSS 2013, IEEE ETFA 2013, DATE 2013 and IEEE SIES'2013.
- Olivier Zendra was program committee chair of ICOOOLPS 2013.
- Olivier Zendra was program committee member for CIEL 2013.
- Olivier Zendra was workshop organization chair for the 3 collocated conferences ECOOP 2013, ECSA 2013 and ECMFA 2013.
- Olivier Zendra was organization committee member for CIEL 2013 (for which he was primary contact), GDRP GPL 2013 and AFDAL 2013.
- The permanent members of TRIO team are reviewers for numerous international Conferences and Workshops and, in particular for the following journals: IEEE Transactions on Industrial Informatics, Real-Time Systems, IEEE Computer Communications, Journal of Discrete Event Systems, Journal of Systems Architecture, Journal of Embedded Computing, Journal of Scheduling, Theoretical Computer Science, ACM Surveys, ACM Transactions on Embedded Computing Systems, Information Processing Letters, Science of Computer Programming.

8.2. Teaching - Supervision - Juries

8.2.1. Teaching

Master : Liliana Cucu-Grosjean, Multiprocessor real-time systems, 30h, Master (M1), University of Lorraine, France

8.2.2. Supervision

PhD & HdR :

PhD : Dorin Maxim, Probabilistic Real-Time Systems, University of Lorraine, December 10th, 2013, Liliana Cucu-Grosjean and Françoise Simonot-Lion

9. Bibliography

Major publications by the team in recent years

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[2] N. NAVET, F. SIMONOT-LION (editors). , *The Automotive Embedded Systems Handbook*, Industrial Information Technology Series, Taylor & Francis / CRC Press, 2008, 488 p. , http://hal.inria.fr/inria-00336166/en

[3] P. CASERTA, O. ZENDRA. *Visualization of the Static aspects of Software: a survey*, in "IEEE Transactions on Visualization and Computer Graphics", 2011, vol. 17, n° 7, pp. 913-933, http://hal.inria.fr/inria-00546158/en

[4] L. CUCU-GROSJEAN, J. GOOSSENS. *Predictability of Fixed-Job Priority Schedulers on Heterogeneous Multiprocessor Real-Time Systems*, in "Information Processing Letters", April 2010, vol. 110, n° 10, pp. 399-402, http://hal.inria.fr/inria-00544642/en

[5] D. MAXIM, L. CUCU-GROSJEAN. *Response Time Analysis for Fixed-Priority Tasks with Multiple Probabilistic Parameters*, in "RTSS 2013 - IEEE Real-Time Systems Symposium", Vancouver, Canada, December 2013, http://hal.inria.fr/hal-00918566

Publications of the year

Doctoral Dissertations and Habilitation Theses

[6] D. MAXIM. , *Analyse probabiliste des systèmes temps réel*, Université de Lorraine, December 2013, http://hal.inria.fr/tel-00923006

Articles in International Peer-Reviewed Journals

[7] F. J. CAZORLA, E. QUINONES, T. VARDANEGA, L. CUCU-GROSJEAN, B. TRIQUET, G. BERNAT, E. BERGER, J. ABELLA, F. WARTEL, M. HOUSTON, L. SANTINELLI, L. KOSMIDIS, C. LO, D. MAXIM. *PROARTIS: Probabilistically Analyzable Real-Time System*, in "ACM Transactions on Embedded Computing Systems", 2013, vol. 12, n° 2s [*DOI : 10.1145/2465787.2465796*], http://hal.inria.fr/hal-00920535

Invited Conferences

[8] L. CUCU-GROSJEAN. *Independence - a misunderstood property of and for probabilistic real--time systems*, in "Alan Burns 60th Anniversary", York, United Kingdom, N. AUDSLEY, S. BARUAH (editors), March 2013, http://hal.inria.fr/hal-00920504

[9] L. CUCU-GROSJEAN. *Probabilistic real-time scheduling*, in "ETR 2013 - Ecole d'été temps réel", Toulouse, France, August 2013, http://hal.inria.fr/hal-00920517

[10] L. CUCU-GROSJEAN. *Probabilistic real-time systems*, in "RTNS 2013 - 21st International Conference on Real-Time Networks and Systems", Sophia Antipolis, France, ACM, October 2013, http://hal.inria.fr/hal-00920513

International Conferences with Proceedings

[11] R. DAVIS, L. SANTINELLI, S. ALTMEYER, C. MAIZA, L. CUCU-GROSJEAN. *Analysis of Probabilistic Cache Related Pre-emption Delays*, in "ECRTS - the 25th Euromicro Conference on Real-time Systems", Paris, France, July 2013, http://hal.inria.fr/hal-00920913

[12] D. MAXIM, L. CUCU-GROSJEAN. *Response Time Analysis for Fixed-Priority Tasks with Multiple Probabilistic Parameters*, in "RTSS 2013 - IEEE Real-Time Systems Symposium", Vancouver, Canada, December 2013, http://hal.inria.fr/hal-00918566

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International Symposium on Industrial Embedded Systems", Porto, Portugal, IEEE, June 2013, pp. 241-248 [*DOI :* 10.1109/SIES.2013.6601497], http://hal.inria.fr/hal-00920538

Books or Proceedings Editing

[14] L. CUCU, R. DAVIS (editors). , *Proceedings of 1st International Workshop on Mixed-Criticality Systems*, University of York, December 2013, 90 p. , http://hal.inria.fr/hal-00920923

Other Publications

[15] E. GROLLEAU, J. GOOSSENS, L. CUCU-GROSJEAN. , *On the periodic behavior of real-time schedulers on identical multiprocessor platforms*, 2013, http://hal.inria.fr/hal-00920529

[16] C. MAXIM, A. GOGONEL, D. MAXIM, L. CUCU. , *Estimation of Probabilistic Minimum Inter-arrival Times Using Extreme Value Theory*, January 2013, 6th Junior Researcher Workshop on Real-Time Computing (JRWRTC 2012) in conjunction with the 20th International Conference on Real-Time and Network Systems (RTNS 2012) Pont-à-Mousson, France, November 8-9, 2012, http://hal.inria.fr/hal-00766063