Inria Associate Teams programme

Annual report

(max. 6 pages)

Associate Team acronym: EQUAVE

Period of activity: *1st year.*

Principal investigator (Inria): Loïc Hélouët, *SUMO Team, INRIA Rennes*

Principal investigator (partner): S. Akshay, *IIT Bombay, India*

Other participants:

Blaise Genest, *SUMO Team, CNRS - IRISA, Rennes, DR2 (senior researcher)*
Nathalie Bertrand, *SUMO Team, INRIA Rennes, CR1 (senior researcher)*
Hugo Bazille, *SUMO Team, PhD Student (2016-2019, INRIA Grant)*
Victor Roussanaly, *SUMO Team, PhD Student (2017 - 2020, ENS Grant)*

S. Krishna, *IIT Bombay, Professor (permanent position)*
Sparsa Roychowdhary, *IIT Bombay, PhD Student (2016-2020)*
Khushraj Madnani, *IIT Bombay, PhD Student (2013-2018)*

Teams' website: http://www.irisa.fr/sumo/EQUAVE/

Key Words:

A- **Research themes on digital science:** *(at most 5 keywords)*
  - **A1.2.2 Supervision**
  - **A1.3 Systèmes distribués**
  - **A2.4.2 Model checking**
  - **A7.1 Algorithmique**
  - **A7.2 Logique**

B- **Other research themes and application areas:** *(at most 5 keywords)*
  - **B1.1.9 Biologie computationnelle**
  - **B5.2.2 Chemin de fer**
  - **B7 Transport et Logisitique**

1. Abstract of the scientific program

The main objective of the EQUAVE project is to study efficient techniques for quantitative verification of cyber-physical systems, and develop efficient algorithms for models of such systems that involve time and/or randomness. A first and immediate challenge is to have good models for such systems that would capture the necessary features while remaining tractable. In this project, we plan to focus on classical as well as new models including Markov decision processes, stochastic timed games, and different variants of timed and concurrent systems. Indeed one objective of the project is to classify the problems and models of cyber-physical systems in terms of tractability.

The project is organized along three main research directions: The first direction is dedicated to **timed systems**, with an emphasis on efficiency of algorithms for the verification of timed properties of concurrent systems. The second line of research will consider the **control of stochastic models**. The third line of research will focus on models with both characteristics:

Obj 1: Efficient Algorithms for Timed and Concurrent Models: In the untimed setting, a usual solution to master complexity of distributed systems is to consider models with restricted use of concurrency, such as Free-choice Petri nets [EsparzaD95] where algorithms are often polynomial, or more recently *negotiations* [EsparzaD13], for which termination can be reduced to efficient application of reduction rules [EsparzaMW16, EsparzaMW17] leading to polynomial algorithms. So far, time in negotiations has not been considered and our first target would be towards extending the model with timing information in a sensible manner. We plan to work on it **in the first year**, starting with our recent work on timed concurrency models with free choice [AHP16, AHP18]. Another topic that we plan to address in **years 2 and 3** is recoverability in a timed but unstable world. We consider models for timed systems depicting correct but idealized behaviors that may not be preserved if unexpected delays occur. In real systems such as metro rail networks, a system does not stay in a degraded situation, and often tries to get back to the ideal behavior through corrective mechanisms. For models including recovery mechanisms, a key question is the time needed to return to a normal behavior, and the divergence that occurred since disruption. Modeling and verification of such phenomena would complete this objective.

Obj 2: Efficient Control of Stochastic Systems: Quantitative analysis of stochastic systems is known to be extremely hard. Indeed, [I4] showed that checking whether the trajectory of a Markov Chain (representing e.g. a given plan for robots) satisfies that the probability to be in a given (bad) state is never higher than a given threshold is as hard as a long-standing open problem on linear recurrence sequences, called the Skolem problem. The decidability of this question has been opened for more than 40 years. On the other hand, there exists a PTIME algorithm [Tiwari04] to check the same question provided that the initial distribution is not fixed but allowed to vary in the given space (a kind of typing result for stochastic systems). **In the first year** of the project, we plan to extend this typing approach to handle Markov Decision Processes (MDPs), that is, to control stochastic systems. In the **year 2 and 3**, we will consider another approach to obtain efficient algorithms, through the use of approximations. In this respect, we plan to extend the efficient algorithm for the isolation problem in Markov Chains [ChadhaKV14], which approximates its quantitative verification, towards MDPs.

Obj 3: Timed & stochastic games: Time and probabilities are two natural quantitative features. They are present in models such as probabilistic timed automata and their game extensions, for which verification algorithms exist, and are implemented, e.g. in PRISM tool [KNP02]. However, when time and probabilities are mixed, i.e. when delays are randomized, the models become more complex from an analysis viewpoint. Several contributions aim at defining large classes of stochastic timed games for which verification problems are decidable [BF-icalp09, R5]. So far, the complexity picture is still open.

Recent advances on the understanding of the purely stochastic model (with no players involved) [R4] should help to progress on stochastic timed games. However, while this model provides most of the features needed to represent real systems, it is quite challenging, as even basic theoretical questions are hard to tackle. Our goal is to identify where the decidability frontier lies for timed stochastic 2 player games. Recent results [R4, BBBC-RR17] indicate that quantitative questions can be decided for stochastic timed models. Our objective is to explore whether these positive results extend to the game setting. We will first consider the restricted case of stochastic timed games where player 1 has no choice. For the general case, we will need new techniques as the existing ones are unlikely to extend. These new analysis techniques will be developed in **years 2 and 3.**

Applications: This project will consider practical applications in the domain of networks of automotive systems (metros and multi-modal transport systems). These systems are by nature distributed, timed, and subject to random perturbations (delays, incidents). We will also consider biological systems, that are stochastic and distributed systems where quantities and parameters such as the size of a population of cells plays an important role in the dynamics of the system.

2. Scientific progress

Obj 1: Efficient Algorithms for Timed and Concurrent Models. With S. Akshay, we have progressed our work on efficient algorithms for timed and concurrent models. First of all, a joint work on robustness of Free-Choice time Petri nets was accepted in the *Journal of Logical and algebraic Methods in Programming* [AHP18]. In this paper, we prove that firability of a particular transition and termination are decidable for a subclass of free-choice time Petri nets. We also prove that robustness of these properties (whether a property still holds if time measurement is imprecise) are decidable. The proof technique brings back questions on timed processes to questions on untimed processes, and can be checked by comparing coverability trees of a time Petri net and of its enlargements.
We have pursued this work, to prove that properties such as boundedness (whether a system uses a finite amount of resources) were also decidable in this setting. The question is more involved, as it cannot be answered directly from coverability trees, and requires to highlight some growing sequences of transitions.
A second contribution this year was to initiate a work on **resilience of timed systems**. The main objective of this work is to establish a formal framework to study the effects of delays on timed systems. In particular, one wants to know whether after a perturbation causing an unexpected delay, a timed system can return to a situation without delays. For timed automata, the problem can be considered as a timed language problem, i.e. ask whether every timed word depicting a perturbed execution has a suffix that corresponds to a suffix of a timed word in the original language. Unsuprisingly, this question is undecidable in general. However, if the question considers timed executions instead of timed words, the problem becomes decidable. Providing efficient algorithms to address resilience questions could find applications for regulation of transport systems.

Obj 2: Efficient Control of Stochastic Systems. With S. Akshay [AGV18], we have extended the typing approach of [Tiwari04] to control stochastic systems, and more precisely Markov Decision Processes (MDPs). The control problem is to keep a distribution of the MDP inside a safe polytope. Interestingly, we get an efficient polynomial time complexity to check whether there exists a distribution, from which there exists a controller keeping the MDP in the safe polytope. This is surprising as the same question starting from a given distribution is not known to be decidable, even if the controller is fixed. Also, we have a co-NP complexity for deciding whether for every initial distribution, there is controller keeping the MDP in the safe polytope. Finally, we showed that an alternative representation of the input polytope allows us to get a polynomial time algorithm for safety from all initial distributions.

During the sojourn of Adwait Godbole, we have considered control for a population of agents that all follow the same finite state protocol and are controlled uniformly: the controller applies the same action to every agent. The framework is largely inspired by the control of a biological system, namely a population of yeasts, where the controller may only change the common environment of a population of cells. We study a synchronisation problem for such populations: no matter how individual agents react to the actions of the controller, the controller aims at driving all agents synchronously to a target state. We have provided algorithm to synthesize a controller for such population, when possible. We proved that our controller leads all the agents in the target state in polynomial time (w.r.t. the number of agents), and that this bound is optimal. This work is submitted to the journal LMCS. Efficiency comes from the fact that instead of considering the systems made of thousands of agents, which would be infeasible in practice, we can handle the combinatorial explosion of the number of agents symbolically by using parameterized systems. As far as we know, this is one of the first results on the control of parameterized systems.

3. Next year's work program

Efficient algorithms for Timed Negotiations:
We will progress the work on timed negotiations to obtain efficient algorithms based on novel efficient timed reduction techniques. We plan an internship on this topic from May to July 2019.

Resilience of timed systems:
We will progress the work on resilience of timed systems initiated in 2018. We want to define the boundaries for a set of questions on timed automata first (can a system recover from a delay in any of its states? Is there a controller that ensures recoverability? ...). Then we want to extend this work to a concurrent and efficient setting.

Coverability and boundedness of Free-Choice time Petri net:
We will progress our work on Free-choice time Petri nets initiated in 2018. We want to design efficient algorithms to decide boundedness and coverability of FC-TPNs, and the robustness of these properties to time enlargement and shrinking. We have already answered close questions (firability of a transition and termination), that were amenable to decision procedures on the coverability tree of an untimed net. Answering theses new questions is more involved, as timing may influence the consumption rate of tokens in a net and cannot be abstracted as easily as for firability and termination.

Controlling a MDPs:
We are working on the escape problem: instead of wanting to stay in safe quantitative polytope, we want to escape such a polytope. The most promising question here seems to be whether for all initial distribution, one can design a controller to escape the quantitative polytope.

Controlling a Population:
We are working with Adwait Godbole on characterizing protocols for which there exists controller working in logarithmic time in the number of agents. We plan to submit a paper next year.

4. Record of activities

May 2018	B. Genest visited S. Akshay at IIT Bombay for 10 days. This was the occasion to progress work in Objective 2.
May - July 2018	Adwait Godbole visited the SUMO team for an internship. His internship topic was control for population protocols.
June 2018	S. Akshay visited the SUMO team for a week.
October 2018	L. Hélouët visited S. Akshay and S. Krishna at IIT Bombay and IIT Delhi. This was the occasion to progress work on Free-choice time Petri nets, and to open new research direction on robustness of timed systems.

5. Production & Impact

5.1. Joint publications

[AGV18] S. Akshay, Blaise Genest, Nikhil Vyas, *Distribution-based objectives for Markov Decision Processes*. LICS 2018, 36-45, ACM/IEEE, 2018

[AHP18] S. Akshay, Loïc Hélouët, R. Phawade, *Combining Free Choice and Time in Petri Nets*, Journal of Logical and Algebraic Methods in Programming, 2018.

Ongoing work

[Ongoing1] Nathalie Bertrand, Miheer Dewaskar, Blaise Genest, Hugo Gimbert, Adwait Godbole. *Controlling a Population,* submitted.

[Ongoing2] S. Akshay, Blaise Genest, Loïc Hélouët, *Resillience in timed systems.*

[Ongoing3] S. Akshay, Loïc Hélouët, Ramchandra Phawade, *Boundedness and coverability in Free-Choice Time Petri nets.*

5.2. Software : *N/A*
5.3. Patents *N/A*
5.4. Demos & videos *N/A*

5.5 Current position of students and postdocs involved in the associate team

- Hugo Basille (PhD, SUMO) : defense planned in 2019
- Victor Roussanaly (PhD, SUMO) : defense planned in 2020.
- Khushraj Madnani (PhD, IIT Bombay) : defense planned in 2019. Could apply for an INRIA Post-doc position in the SUMO team.

5.6. Other forms of impact

The SUMO team is identified at IIT Bombay as a destination for internships for students in they 2nd and 3rd year. We propose several internships each year, and our offers are forwarded to students.

6. Non- Public Information

N/A

7. Changes on the Team

The composition of the team and its objectives remain unchanged.

8. Budget requested for the coming year

	Cost/unit	Total cost
Visit of 2 Indian interns in the SUMO team (May-July 2019)	1250	2500
Visit of an Indian PhD in the SUMO team (Feb. 2019)	1000	1000
Visit of Hugo Basille (PhD, SUMO) to IIT Bombay	2500	2500
Visit of B. Genest to IIT Bombay (May 2019)	2000	2000
Visit of L.Hélouët to IIT Bombay (Oct. 2019)	2000	2000
Total		10000

We plan the visit of a PhD student to India next year, and of two permanent researchers to India. We plan to receive the visit from S.Akshay next year, as well as 2 interns.

The total amount requested for year 2019 is **10 000 euros.**

The SUMO team had fruitful collaborations with members from the Informel LIA (Indo-French Formal Methods Lab, 2012-2016), and continues to have connections with ReLaX[1] an international joint research unit between CNRS, Université de Bordeaux, École Normale Supérieure Paris-Saclay, Chennai Mathematical Institute and Institute of Mathematical Sciences in Chennai.

The Relax project is eager to help in the development of Indo-French collaboration in theoretical computer science, beyond the founding partners of the UMI.

Thanks to the recent collaborations of S. Akshay in IIT Delhi, we are also building relations with researchers of IIT Delhi. A long term objective is to launch larger projects, possibly in the CEFIPRA Collaborative Research Programme, with more partners in India and in France. During the lifetime of EQUAVE, we will devote a part of our efforts to dissemination of our ideas and results. For this, we plan visits to other labs in India and in France to give talks on our ongoing work and make it accessible to a wider audience. Further, we plan to organize a seminar in France during the second or third year of EQUAVE. Organizing such events are also important for critical impact and future extensions of our project.

[1] http://projects.lsv.ens-cachan.fr/relax/

Appendix : references

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