# Scientific Report

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| Nationality | Colombian |
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| Period of the fellowship | 01/03/2013 to 31/12/2013 |

# I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

*Computational ecology* is a recent field whose objective is to construct models of ecological systems (e.g., ecological communities and metapopulations) to gain understanding of the real systems. These models can be analysed with several computational tools to make predictions about the dynamics of the real systems. The biggest motivation of constructing these models is to simulate large-scale experiments that would be too costly or unethical to perform over a real ecosystem.

There are several computational models suitable to model ecological systems such as Petri nets, process calculi and P systems. *Process-calculus approaches* are a promising direction because they are suited with different techniques such as process equivalence (i.e., bisimulation), model checking and simulation. In addition, some process calculi offer different extensions to model discrete time, continuous time, hybrid time, stochastic behaviour, non-deterministic behaviour or a combination of the above.

Anna Philippou et al. have developed a process calculus, called PALPS, to model spatially-explicit ecological systems [1]. My work consisted on building on this work in two directions: (1) I developed a methodology for simulating and model-checking the models. (2) I applied the framework for the analysis of the *varroa mite* parasite that atacks honey bees, and for the *Eleonora Falcon* which is a species whose conservation in the Mediterranean region is of special interest.

I strongly believe that this study complements existing ecological studies and offers important insights for dealing with these problems. It has already been discussed in the literature that process calculi offer several advantages over the ordinary-differential equations. I confirmed that PALPS bears the promise of producing a useful framework for reasoning about ecological systems. As an example, we showed that it is possible to reason about probabilistic temporal properties of PALPS processes; for instance, the probability of extinction of a species.

### Time Schedule

**Phase 1:** We performed a thorough literature review to establish the state-of-the-art of tools and methodologies to simulate and analyze biological and ecological process calculus models. March 2013.

**Phase 2:** We made an investigation of the algorithms for simulating the behaviour of processes defined in PALPS, as well as the usage of suitable temporal logics to express the correctness criteria of the systems in question and associated model-checking algorithms. Subsequently, we reviewed various methodologies proposed in the literature for modelling and analysis of ecological systems (e.g., process algebraic frameworks and P-Systems) to assess their strengths and weaknesses for reasoning about metapopulation systems. Finally, we developed a translation of PALPS into PRISM for model checking We wrote and submitted a journal paper with the these results. April 2013

**Phase 3:** We performed a literature review on Population Ecology and distiled the basic characteristics of metapopulation systems in order to specify their key characteristics and the factors that influence their behaviour. Based on this study, two representative case

studies were selected and were used as a benchmark. We extended PALPS to model the case studies. This extension was guided by the case studies which served as a tool for evaluating the effectiveness of PALPS and distinguishing the necessary extensions for reasoning about realistic metapopulation systems (e.g., the notion of *policy*). A policy is an entity for specifying orderings between the different activities within a system. We developed a new translation of PALPS into PRISM for model checking that supports the notion of policies. At the end of this phase, we wrote and submitted a conference paper with the results. May - June 2013.

**Phase 4:** We extended the calculus to deal with models in which there is a big number of individuals by representing the number of individuals symbolically. Using this extension, we modeled the ecosystem of the Eleonora Falcon. I also co-supervised a Master student doing a thesis on this subject during this period. July 2013 - November 2013.

**Phase 5:** We assessed the results obtained in the previous phases, in addition to feedback obtained on the articles. We identified strengths and weaknesses of the approach as well as directions for future work, we wrote a technical report with these new results, and completed the ERCIM reports. The results contained on the technical report are to be published next year. December 2013.

### References
[1] Margarita Antonaki and Anna Philippou. A process calculus for spatially-explicit ecological models. EPTCS 100, 2012, pp. 14-28.
[2] The P Systems Website. http://ppage.psystems.eu/

## II – PUBLICATIONS DURING YOUR FELLOWSHIP

- A. Philippou, M. Toro, and M. Antonaki. Simulation and Verification for a Process Calculus for Spatially-Explicit Ecological Models. Scientific Annals of Computer Science, 23(1):119–167, 2013.

### Abstract
We propose PALPS, a Process Algebra with Locations for Population Systems. PALPS allows us to produce spatially-explicit individual-based ecological models and to reason about their behavior. PALPS has two abstraction levels: At the first level, we may define the behavior of an individual of a population and, at the second level, we may specify a system as the collection of individuals of various species located in space. In PALPS, the individuals move through their life cycle while changing their location and interact with each other in various ways such as predation, infection or mating. Furthermore, we propose a translation of a subset of PALPS into the probabilistic model checker PRISM. We illustrate our framework via models of dispersal in metapopulations and by applying PRISM on PALPS models for verifying temporal logic properties and conducting reachability and steady-state analysis.

- A. Philippou, M. Toro. Process Ordering for a Process Calculus for Spatially-Explicit Ecological Models. In Proc. of the International Symposium on Modelling and Knowledge Management for Sustainable Development. September, 2013. Madrid, Spain.

### Abstract
In this paper we extend PALPS, a process calculus proposed for the spatially-explicit

individual-based modeling of ecological systems, with the notion of a *policy*. A policy is an entity for specifying orderings between the different activities within a system. It is defined externally to a PALPS model as a partial order which prescribes the precedence order between the activities of the individuals of which the model is comprised. The motivation for introducing policies is twofold: one the one hand, policies can help to reduce the state-space of a model; on the other hand, they are useful for exploring the behavior of an ecosystem under different assumptions on the ordering of events within the system. To take account of policies, we refine the semantics of PALPS via a transition relation which prunesaway executions that do not respect the defined policy. Furthermore, we propose a translation of PALPS into the probabilistic model checker PRISM. We illustrate our framework by applying PRISM on PALPS models with policies for conducting simulation and reachability analysis.

- A. Philippou, M. Toro. State-Vector Semantics for a Synchronous Extension of a Process Calculus for Spatially-Explicit Ecological Models. Tech. Report. University of Cyprus. To be released in 2014.

**Abstract**
In this paper we extend PALPS with a synchronous parallel operator and state-vector semantics. We also provide a translation into PRISM for simulation and model checking. We use this extension of PALPS to model the ecosystem of a species in danger.

# III – ATTENDED SEMINARS AND CONFERENCES

- 11th International Conference on Software Engineering and Formal Methods (SEFM 2013). September 25-27, 2013, Madrid, Spain

- 2nd International Symposium on Modelling and Knowledge Management for Sustainable Development at Madrid, Spain, 24 September 2013.

- ABCDE Annual Seminar at Athens, Greece, 30-31 October 2013.

# IV – RESEARCH EXCHANGE PROGRAMME (REP)

- One week visit to the Comète team, LIX at École Polytechnique de Paris, France. Scientific coodinator: Catuscia Palamidessi. June 2 – 9 2013. I discussed with Palamidessis's team about the usage of suitable temporal logics to express the correctness criteria of the systems in question and associated model-checking algorithms for PALPS.

- One week visit to the CNR research institute at Pisa, Italy. Scientific coordinator: Stefania Gnesi. November 11 – 15 2013. I discussed with Gnesis's team about the extension of PALPS to deal for models in which there is a big number individuals by representing the number of individuals symbolically.