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PROJECT PERIODIC REPORT

Grant Agreement number: 600708

Project acronym: QUANTICOL

Project title: A Quantitative Approach to Management and Design of Collective and Adaptive Behaviours

Funding Scheme: Small or Medium scale focused research project (STREP)

Topic: ICT-2011 9.10: FET-Proactive `Fundamentals of Collective Adaptive Systems' (FOCAS)

Date of latest version of Annex I against which the assessment will be made: 10/03/2014

Periodic report: 1st X 2nd ☐ 3rd ☐ 4th ☐

Period covered: from 01/04/2013 to 31/03/2014

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[1] Usually the contact person of the coordinator as specified in Art. 8.1. of the Grant Agreement.

[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate) [3]:

  X has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations.

  ☐ has failed to achieve critical objectives and/or is not at all on schedule.

- The public website, if applicable

  X is up to date

  ☐ is not up to date

- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 3.4) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 3.2.3 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator: ....Jane Hillston..

Date: ......30.../ .....05...../ .....2014.....

For most of the projects, the signature of this declaration could be done directly via the IT reporting tool through an adapted IT mechanism and in that case, no signed paper form needs to be sent

[3] If either of these boxes below is ticked, the report should reflect these and any remedial actions taken.

QUANTICOL

A Quantitative Approach to Management and Design of Collective and Adaptive Behaviours

http://www.quanticol.eu

D7.1

Periodic project report for months 1–12

Revision: 1.0; May 30, 2014

Author(s): Jane Hillston (UEDIN)

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Project number: 600708

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Part. no.	Participant organisation name	Acronym	Country
1 (Coord.)	University of Edinburgh	UEDIN	UK
2	Consiglio Nazionale delle Ricerche – Istituto di Scienza e Tecnologie della Informazione "A. Faedo"	CNR	Italy
3	Ludwig-Maximilians-Universität München	LMU	Germany
4	Ecole Polytechnique Fédérale de Lausanne	EPFL	Switzerland
5	IMT Lucca	IMT	Italy
6	University of Southampton	SOTON	UK
7	Institut National de Recherche en Informatique et en Automatique	INRIA	France

COOPERATION

Contents

1 Publishable Summary

Project Description The design of collective adaptive systems (CAS for short) must be supported by a powerful, well-founded framework that offers formal modelling and quantitative analysis. CAS consist of a large number of spatially distributed heterogeneous entities with decentralised control and varying degrees of complex autonomous behaviour. These entities or agents may be competing for shared resources even when collaborating to reach common goals. Often humans are both agents within such systems and end-users standing outside them. As end-users, they may be completely unaware of the sophisticated underlying technology needed to fulfil critical socio-technical goals such as effective transportation, communication, and work. The pervasive but transparent nature of CAS, together with the importance of the goals that they address, mean that it is imperative that thorough *a priori* analysis of their design is carried out to investigate all aspects of their behaviour, including quantitative and emergent aspects, before they are put into operation. We want to have high confidence that, once operational, they can adapt to changing requirements autonomously without operational disruption. Unfortunately, the defining characteristics of these systems mean that their (possibly non-linear) behaviour is often highly unpredictable or counter-intuitive. Formal, scalable, quantitative analysis, which provides multiple perspectives on system behaviour while being based on well-established reasoning techniques, is imperative to master such complex systems.

One of the main goals of the project is the development of an innovative formal design framework that provides a unique specification language for CAS and a large variety of tool-supported, scalable quantitative analysis and verification techniques. This design framework will also enable and facilitate experimentation and discovery of new design patterns for emergent behaviour and control over spatially distributed CAS. It will support both agent-based modelling techniques and equation-based techniques starting from system specifications at the individual (micro) level.

The work in the project is driven by smart city applications which can be very large scale CAS comprised of heterogeneous entities with spatially inhomogeneous distribution. This demands computationally scalable approaches. Therefore, the primary focus of the project is on the extension and exploitation of mean field and fluid flow techniques rather than simulation-based approaches. However, the latter play an important role in the exploration of smaller systems and in the validation of new techniques.

Figure 1 shows the QUANTICOL vision of the development of the research in this project. Starting from the basement of the castle, the principal case studies will drive the development of theoretical extensions of mean field and fluid approaches tackling four distinct challenges: 1) scalability 2) (self-)adaptivity 3) spatial inhomogeneity and 4) design and control of emergent behaviour. Meanwhile, higher up in the castle, process algebraic verification techniques will be developed and integrated into a uniform design framework supported by analysis and verification tools exploiting existing results in mean field and quantitative formal methods based on process algebra and temporal logics. Subsequently, the new theoretical results will be transformed into extensions of the tools that populate the framework, making them available in a software engineering context. The techniques and tools will then be tested and validated on various case studies ranging from small exemplifying systems (for the purpose of illustration of the techniques and for tutorials), to existing benchmarks and variants of the smart city applications that were driving the theoretical parts of the project. Furthermore, the experience in the design and analysis of the wide range of case studies will be exploited for the development of design and analysis pathways that will guide software engineers in the development of CAS for smart cities.

Research Objectives To ensure that the work proposed in the QUANTICOL project is feasible and verifiable, the overall working structure reflects the major QUANTICOL objectives. This makes the achievement of each objective measurable by the results of the corresponding work package(s).

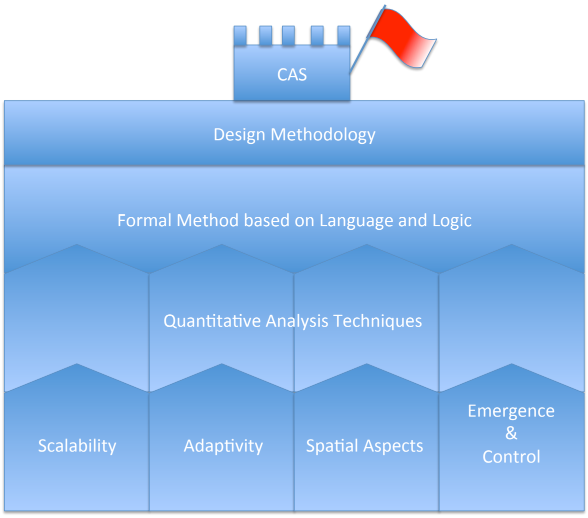


Figure 1: Quanticol research vision

The main objectives and the work packages are listed below:

1. Development of a rigorous mathematical framework to engineer emergent behaviour in multi-scale systems.
2. Definition of a formal framework enabling the description of systems with spatial aspects with a process algebraic language, and supporting different kinds of representation of space and abstractions based on mean field techniques in an automatic way.
3. Development of stochastic temporal logics and novel forms of scalable model-checking approaches exploiting mean-field/fluid flow approximations that can address the verification of properties at the macro and micro level and their combination.
4. Development of a generic language offering linguistic support for high-level CAS modelling, expressing adaptivity and spatial awareness and enabling emergent behaviour.
5. Design and implementation of a software tool suite will be pursued which will provide a unified formal framework for the specification, analysis, and verification of models of CAS.

The target outcomes of the project include a scalable, quantitative design and verification framework and tools for large heterogeneous CAS to make model-based design of CAS of unprecedented size and complexity feasible where traditional agent-based approaches, reliant on extensive simulations, would be prohibitively costly. Potential outcomes of our case studies include enhancing the design of urban transportation systems through formal design and verification, exploiting mean field techniques, in order to demonstrate that they operate in a safe and controlled way whilst also meeting user demand. Similar considerations hold for the design of smart grid applications that adaptively maintain the lowest possible peak demand while providing clients with the best possible service in a safe and reliable way.

Major Achievements During the First Reporting Period The first year of the QUANTICOL project has been focussed on developing foundations and exploratory work to deepen our understanding of the research context both in terms of the application domain and the mathematical and formal techniques which we will build upon. The project has achieved the following major results:

1. Many of the CAS case-studies selected for the project are characterised by the presence of multiple scales. These scales can be temporal – for example coexistence of fast and slow dynamics

– or organisational – for example, a centralised controller and many individuals, or a structured hierarchy of systems. We investigated different model reduction techniques for multi-scale models including: reduction techniques for fluid models, such as perturbation techniques, for stochastic models and fluid models with immediate transitions; techniques dealing with multiple population scales and with multiple organisational scales such as those found in systems-of-systems.

In the context of control of electricity networks:

- We considered the multi-scale problem of jointly scheduling generation and storage or demand-response in energy systems with distributed generation and remote switching of user appliances.
- We studied game-theoretic approaches to a two-stage market model where consumers react to prices or congestion signals.

2. We conducted a survey of the state-of-the-art and identified key issues in finding suitable spatial representations and related general mathematical methods used to construct spatial models. The survey reports on what representations are present in the modelling literature, drawing from a number of disciplines, and developing a classification of the techniques involved. The classification has been applied to the project case studies, providing insight into the more suitable models and related analysis techniques for space-aware analysis.

3. We have investigated the foundations of scalable verification techniques by developing several innovative and efficient fluid model-checking techniques that address local, global and mixed stochastic properties of CAS and their individual components, obtaining the following main results:

   - Consolidation of the CSL Fluid Model Checking approach by considering steady state properties and by introducing the next-operator of the logic.
   - Lifting local properties to global properties, developing a new method based on a second order fluid approximation known as linear noise approximation.
   - Development of a new numerical method in the form of a tool chain for stability analysis of stochastic population models derived from suitable process algebra specifcations.
   - Development of the foundations of a scalable on-the-fly model-checking procedure for verifying bounded PCTL formulas based on mean-field and fast simulation results in discrete time, implemented in the prototype model-checker FlyFast.
   - Development of two powerful analysis tools based on statistical model checking and recent advances in machine learning, tackling problems in system design (searching parameter spaces) and the impact of uncertain parameters on truth of temporal logic formulae.
   - Literature study on logical approaches to the treatment of spatial information.

4. We have designed a set of linguistic primitives for the language CAS-SCEL. These primitives have been presented in the context of a set of design principles and interaction patterns specific to CASs and they have been included in four experimental process specification languages: StocS, PALOMA, PEPA-S and Stochastic HYPE. We have studied a number of linguistic primitives, bearing in mind the focus on fluid semantics, including:

   - Broadcast, multi-cast and uni-cast primitives to allow for more dynamic and decentralised communication patterns among agents.
   - Predicate-based communication that aims at communication to ensembles of components determined at execution time in a multi-cast fashion.

- The use of an explicit knowledge-base to facilitate the realisation of adaptation patterns by separation of the adaptation data from other data, and to model the component's view of (and awareness of) the environment.
- The introduction of 'perception functions' to represent the environment and its influence on the possible actions of agents.
- Introduction of notions of spatial representation and movement of agents based on discrete locations and continuous space.

5. We have defined application requirements and system needs for the case studies. In particular, for each of the three case studies of the project, bike-sharing, public bus transportation and smart electricity grid, we have identified requirements and benefits of modelling, sources of publicly available data and research challenges for each case study from the point of view of CAS. Furthermore, we have identified the set of software tools, libraries and programming languages that have been, or are intended to be used across the project. We also considered which tools are envisaged to require interoperability and we developed a preliminary plan to implement this interoperability in a common framework.

During the first months the QUANTICOL website was established to communicate the goals and progress of the project in an easily accessible way. The QUANTICOL project has published widely and prolifically in its first year with 19 publications in key journals and conferences in different scientific communities ranging from quantitative modelling, formal methods, software engineering and collective adaptive systems. Moreover, a number of project technical reports have been published that make our most recent results available within and outside the project in a timely manner. A short overview article of the project was presented at the first FoCAS workshop in Taormina and collaboration and exchange with other European projects, ASCENS, CASSTING and Smart Society, has been set up through participation in joint meetings.

Expected results and their potential impact Our long term research vision is the development of a comprehensive software engineering environment, supporting a model-based design methodology for the development of CAS for smart city applications taking non-functional properties into account. The QUANTICOL project contributes to this vision by laying the basis for the development of such a formal quantitative modelling framework. Among the main expected results we would like to mention:

- A quantitative model-based design and verification framework that provides a formal modelling language, a temporal logic-based language for the formulation of performance related properties of CAS, and a extensive set of scalable analysis and verification methods. These methods should combine and extend quantitative techniques from process algebra, performance analysis, simulation, and mean-field approaches with techniques from the field of complex adaptive systems. We will develop a software environment supporting modelling, analysis, verification and comparison of CAS designs.

- The extension of the above framework to the analysis of CAS characterised by inhomogeneous spatial distribution of components. Such arrangements of components arise in the context of smart cities, as exemplified by our case studies.

- The development of design principles and analysis pathways for the prediction and control of emergent and (self-)adaptive behaviour and the development of support for such principles and pathways in the context of the formal modelling and verification framework mentioned above.

Currently, work on design of CAS is spread across a number of different disciplines with limited opportunities for systematic comparison or combination of techniques. We see our formal framework as an essential first step towards addressing this problem. The project case studies are an integral part of this. On the one hand, they provide a connection to real-world problems which set the goals for the theoretical research of the project. On the other, they will serve as applications to validate the design framework and provide channels of communication to the wider CAS community.

1.1 Project website

Further details of the project can be found on our website `www.quanticol.eu`.

1.2 Project partners

	Partner	Acronym	Site leader	Dates
1 (Coord.)	University of Edinburgh	UEDIN	Prof Jane Hillston	1/4/13 onwards
2	Consiglio Nazionale delle Ricerche – Instituto di Scienza e Tecnologie della Informazione "A Faedo"	CNR	Dr Mieke Massink	1/4/13 onwards
3	Ludwig-Maximilians-Universität München	LMU	Dr Mirco Tribastone	1/4/13 – 31/8/13
4	Ecole Polytechnique Fédórale de Lausanne	EPFL	Prof Jean-Yves Le Boudec	1/4/13 – 31/1/14
5	IMT Lucca	IMT	Prof Rocco De Nicola	1/04/13 onwards
6	University of Southampton	SOTON	Dr Mirco Tribastone	1/9/13 onwards
7	Institut National de Recherche en Informatique et en Automatique	INRIA	Dr Nicolas Gast	1/2/14 onwards

2 Project Objectives for the Period

The first period of the project was intended to be exploratory. The first milestones (MS1 and MS3) for month 12 were initial design work towards a language and logic suitable for modelling collective adaptive systems which are amenable to scalable quantitative analysis (D3.1 and D4.1) and study of the case studies to deepen our understanding of the requirements and objectives associated with considered scenarios (D5.1). The first period has also seen substantial progress towards the second milestone (MS2, scheduled for month 18) which is highly complementary to the first milestone. For MS2 we seek to specify the framework of quantitative analysis which will underpin the language and logic. Substantial progress has been made towards this milestone through a thorough investigation of the literature on multi-scale and spatial modelling, and an identification of the techniques most suitable for incorporation into the project (D1.1 and D2.1). Indeed, this milestone has been reached ahead of schedule.

3 Work Progress and Achievements during the Period

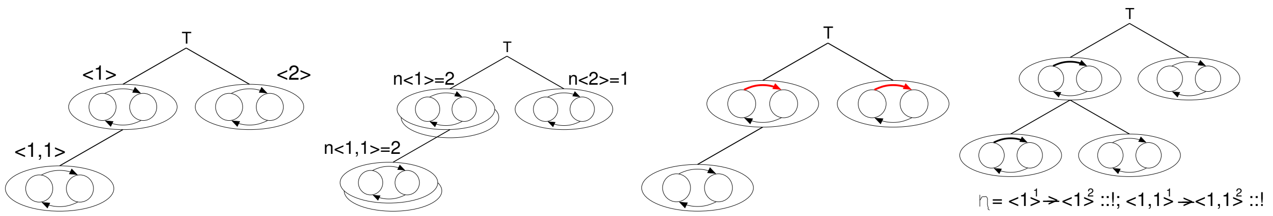
3.1 Work Package 1

The focus of Work Package 1 during the first period has been on investigating issues related to multi-scale modelling, particularly in the context of modelling smart grids. Multiple scales are inherent in many collective adaptive systems (CAS). The different scales may be *temporal*. For example, adjusting the production of a large power plant takes hours while appliances can be switched on or off the instant a signal is received. They may also be *organisational* and represent a hierarchical structure; for example a smart building that contains rooms. Our initial investigation into multi-scale modelling has resulted in a number of publications and a detailed technical report surveying the techniques that are currently available for scalable analysis of multi-scale systems and assessing their feasibility for the future work of the project.

Within temporal multi-scale modelling generally two timescales are assumed, decomposing the model into *fast* and *slow* behaviour. This situation emerges when the states of some entities evolve at a much faster time scale than others. A common tactic is to abstract from the behaviour on one time-scale whilst representing the other in detail. As we consider CAS systems, our emphasis is on scalable analysis techniques related to mean-field approximation. Thus our review of existing techniques focussed on time-scale reduction techniques which can be readily applied to mean-field models. We found that the reduction techniques for deterministic dynamical systems, are much more mature than on-going work on stochastic systems. Thus our review found a number of time-scale reduction techniques that can be readily applied to mean-field models and suggested a number of approaches towards developing analogous techniques for stochastic systems. Initial results in this direction have been developed within the project and published in a paper in which we establish a fluid analysis technique for models with immediate transitions, representing systems in which the fast time scale is so fast that state transitions on that time scale have negligible delay. This technique allows, for example, the analysis of smart grid scenarios with many generators and providers, and is most effective in optimisation problems such as trying to maximise electricity production, subject to environmental constraints such as on pollution or the carbon footprint.

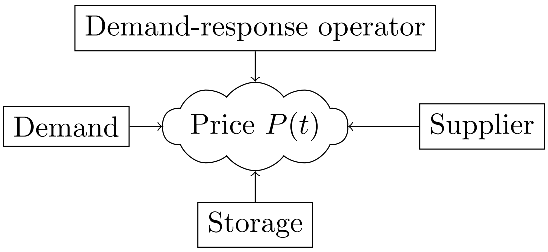
Within organisational multi-scale modelling we identified two cases. Firstly we considered systems in which there are multiple population scales. For example, within a smart grid there might be one centralised controller which interacts with many appliances. We have established that within such systems, when the population grows, the limit is naturally described by a stochastic hybrid system. Project partners EPFL/INRIA and CNR have both previously worked on this area and we developed a stronger understanding of how these previous results are related. In the second case we considered *systems of systems*, systems whose entities may themselves be regarded as systems, to arbitrary depths of hierarchical organisation. Here we have developed a formalism based on nested automata, illustrated in Figure 2, encompassing rich forms of interaction between automata at the same (horizontal) or different (vertical) levels in the hierarchy. This formalism allows us to automatically reduce the complexity of the mean-field equations representing the full system, by exploiting symmetries in the model. This method can be applied iteratively, to construct hierarchical abstractions of systems. We illustrate our method to describe the behaviour of a collection of smart buildings. A paper reporting this work has been accepted for publication.

The final piece of work reported for this work package during the first year concerns control algorithms for electrical systems in the context of renewable energy supplies, illustrated in Figure 3. In this work, which has been accepted for publication, we demonstrate the use of optimization tools for building such algorithms. Specifically we model and deal with two specific challenges: large forecast uncertainties and the presence of delays due to multiple time scales. The study has considered two directions, based on centralized and distributed control respectively. We have developed storage and demand/response management policies, where a central controller sends signals to smart users to adapt the consumption to the production. These policies have been shown to be more robust to forecast

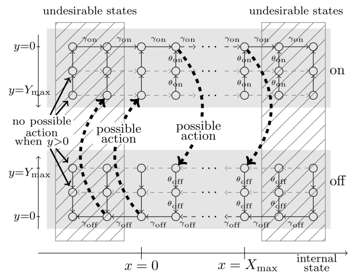


a) b) c) d)

Figure 2: a) A tree of automata defining a system of systems; b) An instance of a system of systems; c) Horizontal interaction; d) Vertical interaction.



(a) Schematic model of the real-time electricity market.



(b) Each flexible load is modelled by a Markov chain.

Figure 3: The real-time electricity market model and the demand-response model.

errors than existing strategies.

Deliverable 1.1, as part of Task 1.1, has been the main objective of Work Package 1 in the first year of the project. It has been successfully completed by its due date. Resource usage is in line with that described for the work package in Annex I. In the original work plan, we planned to divide the work of Task 1.1 in two deliverables; Deliverable 1.1 was intended to be focussed on the case studes while Deliverable 1.2 was to be theory-oriented. It now seems more reasonable to us to try to advance both on the theory and its application to the case studies at the same time. Hence, Deliverable 1.2 will cover both these aspects. It will also incorporate results related to Task 1.2, which focuses on control of emergent behaviour.

We are now extending this work in different directions. First, many of the applications that we consider have elements of *uncertainty*, in the sense that the parameters governing the (stochastic) behaviour may not be known or may vary. We have initiated an investigation and classification of different notions of uncertainty, particularly aiming to understand how they relate to mean field analysis, with application to analysis and verification (WP3). Second, we will pursue our work on optimisation to build a general framework in which these methods can be applied. Finally, we are continuing our work on the smart-grid case-study, building a distributed algorithm for the real-time control of distribution networks (in collaboration with WP5).

3.2 Work Package 2

During the first year of the project the primary focus of Work Package 2 has been on surveying the existing approaches to incorporating spatial aspects within dynamic mathematical models and developing a deeper understanding of which of these approaches may be useful for the further development of the modelling languages and analysis techniques later in the project. Thus the major output of this work package has been a technical report (QUANTICOL TR-QC-05-2014) which reviews a diverse literature including mathematics, ecology, biology and computer science.

Space is important in the QUANTICOL project because the project case studies, especially those

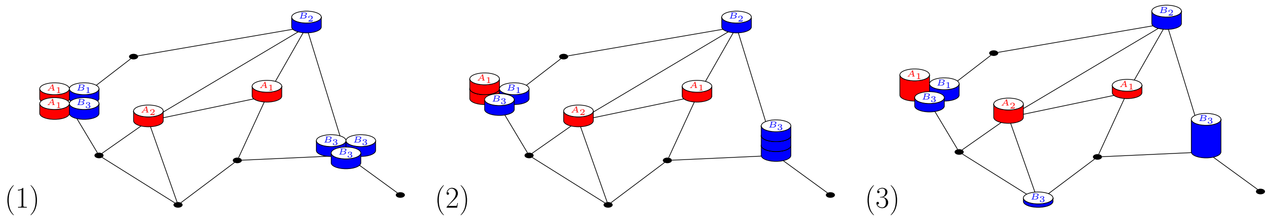


Figure 4: Discrete space: (1) discrete state for each individual; (2) individuals aggregated by state, population count is discrete; (3) individuals aggregated by state, population count is continuous and approximates the discrete population count

related to smart urban transport have strong spatial elements. Therefore the review of the existing work, its scope, applicability and limitations, provides an essential foundation for the future development of QUANTICOL. In particular we have established a classification of the different approaches reviewed. The objective of the classification is to make clear what approaches are available and how they differ from each other in order to guide future work on spatial approaches within the project. Furthermore, the classification has been applied to the initial work that has been done within the project on smart transport case studies, providing valuable insight into the most promising approaches for further study.

The review has considered the availability of mean-field and other approximation techniques for the surveyed spatial modelling techniques, bearing in mind the scalability issues that inevitably arise in CAS.

Essentially there are three distinct approaches to capturing space within dynamic models:

1. Space can be discrete and described by a graph of locations. Depending on the structure of the graph and the parameters associated with locations and movement between locations, discrete space can be classified as regular or homogeneous. Figure 4 illustrates different treatments of individuals and populations in discrete space.

2. Space can be seen as continuous: as Euclidean space in one, two or three dimensions.

3. Space can also be considered abstractly as topological space, whether discrete or continuous and this approach allows for reasoning about concepts such as adjacency and neighbourhoods.

For the QUANTICOL project the first and last approaches appear most promising. We have developed preliminary guidelines arising from the review and classification which have been carried out. These can be summarised as follows.

- Existing mean-field techniques for discrete space often focus on global measures rather than an understanding of spatial heterogeneity. Furthermore, they are often specific to the scenario being modelled, so different specific techniques or more general techniques may be required for QUANTICOL.

- The existing literature uses standard ODE techniques. The ODEs from QUANTICOL models are likely to be more complex and require more advanced techniques, particularly when space is inhomogeneous with respect to time. Moreover, there appear to be no approaches for describing the time and/or space dependencies of a model, or a modelling technique.

- The use of hybrid modelling techniques for modelling space seems infrequent and this is an area for further investigation.

Deliverable 2.1, as part of Task 2.1, has been the main objective of Work Package 2 in the first year of the project and this has been successfully completed by its due date. We have started work on

Tasks 2.2 and 2.3 ahead of schedule. In the case of Task 2.2 which is about process algebraic modelling of space, the work fitted well with the progress in Task 4.1 on the modelling language, and in the case of Task 2.3 which considers parameterisation of space, working with the data from the bus case study stimulated work in this direction. Resource usage is in line with that described for the work package in Annex I. The investigation of abstract space, namely topological and closure spaces, as part of Task 2.1 fits well with the progress on spatial logics in Task 3.1.

We now move on to consider particular analysis techniques for spatial modelling and extensions of these techniques in the context of the project (Task 2.1); to further investigate parameterisation when modelling space (Task 2.3); and to understand and develop language features at the process algebra level for describing space that allow mapping to these spatial modelling and analysis techniques (Task 2.2).

3.3 Work Package 3

Work in the first year of Work Package 3 has been mostly focused on the development of novel scalable approaches to verification of CAS based on mean-field and fluid techniques, corresponding to the main objective of the first phase of Task 3.1. We have had notable success in this area extending previous results, and developing novel model checking techniques which are highly scalable. In addition we have also investigated spatial logics, which allow spatial aspects of dynamic systems to be the focus of verification. Model checking is a powerful technique for the automatic verification of concurrent and distributed systems, so developing efficient and scalable forms of model checking is central to the QUANTICOL framework for CAS.

Project partners were the first to propose *fluid* model checking in the context of properties of single agents within a large population expressed in a subset of the Continuous Stochastic Logic (CSL). During the first year of the project the technique was extended to the whole time-bounded fragment of CSL, and the steady state operator when appropriate. In addition a novel approach has been developed for verifying collective properties expressed in terms of one clock deterministic timed automata. In this work a linear noise approximation is used to verify properties at the global system level. For each individual, an agent model is combined with an automaton expressing the property and the population model is formed by counting pairs of state-property configurations. The evolution of the counting process is given a Gaussian approximation from which the probabilities of interest can be readily computed. This work is in the continuous time population CTMC setting.

Related to this work on verification of specifications of continuous time models, is some further work on the stability of such models. Stability analysis provides important information about the predictability of the dynamics of systems and their sensitivity to parameter values. A new numerical method, in the form of a tool-chain, is proposed for stability analysis starting from a stochastic process algebra specification of agent coordination in a collective dynamic system.

Additionally, we have developed a new verification method for CAS in the DTMC setting, based on an on-the-fly model checking of DTMC models against probabilistic logic (PCTL) formulas. Details are reported in a technical report (QUANTICOL TR-QC-01-2013) and have also appeared as a publication. Again consideration is limited to *bounded* PCTL formulae expressing properties of a single agent (or small set of agents) in a large population combined with a preliminary formulation of *global* properties. The developed on-the-fly model checking algorithm is parametric with respect to the semantic interpretation that is placed on the model, meaning that both an exact probabilistic and approximate mean-field semantics can be used, taking advantage of fast simulation results in the latter case. The approach is supported by a prototype tool, FlyFast, developed within the project during the first year. The use of the approximate model checking technique has been demonstrated on the QUANTICOL bike sharing example. In the discrete setting, we have also worked on estimating the approximation error incurred by the mean-field approach for some classes of models.

A third contribution of WP3 concerns statistical model checking. Here we developed a novel efficient technique and tool to deal with uncertainty in the values of model parameters in a statistically sound way. The approach is based also on recent advances in machine learning and pattern recognition. Work package members also contributed to two tools aimed at providing verification for extremely large systems.

Finally, we conducted a literature study on spatial logics that fit well with the abstract topological and closure spaces addressed in Task 2.1 on spatial representations in WP2. This is reported in a technical report (QUANTICOL TR-QC-01-2014). Furthermore, fluid flow and mean field model checking techniques have also been taken into consideration as one of the factors in the design of the exploratory languages studied in WP4.

All results have been documented in Deliverable 3.1, which has been successfully completed by its due date. Halfway through the first year work on Task 3.2 and Task 3.3 has also started. Task 3.2 deals with abstraction techniques that go beyond fluid approximations such as the development of equivalence relations based on ODEs. Work is in progress on the development of a theory of aggregation of ODEs induced by an equivalence relation over the local states of a process algebra model that captures symmetries in the fluid semantics according to the well-known notion of exact lumpability for ODEs. Task 3.3 deals with the relation between local and global system views and variability analysis in the context of software product lines. In the context of this task an initial feature model of a family of bike-sharing systems has been developed. It is annotated with attributes and global quantitative constraints aiming to minimise the total cost of a chosen configuration and at the same time maximise customer satisfaction and capacity of docking stations. This is particularly useful when the employment of a bike sharing system is considered in a particular city with its own geography and usage patterns.

The research activities within WP3 have proceeded smoothly, there were no major deviations from the initial work plan in Annex I. The resources allocated on the work package have been functional and necessary to the achievement of the results. The work in Task 3.1 will move on to the second phase, focusing on prototype implementations of the techniques and to study their extension to include spatial aspects. Task 3.2 will proceed by studying abstraction techniques and Task 3.3 with the investigation of stochastic extensions of variability analysis. Progress on the latter two tasks will be reported in Deliverable 3.2 in month 30, whereas progress on Task 3.1 will be reported in an internal report at month 36.

3.4 Work Package 4

The focus of work package 4 has been on the exploratory work to support the development of the CAS-SCEL modelling language which will be at the core of the QUANTICOL framework. In particular we have considered design principles for the language and worked on the identification of language *primitives* which are able to address the complex requirements of developing a language rich enough to capture essential features of CAS and yet remain amenable to scalable analysis techniques. Key concerns have been elements such as movement primitives or space abstraction primitives and interaction patterns, such as broadcast communication or anonymous interaction. All these are believed to be necessary in the QUANTICOL case studies and, more generally, in CAS design. Our first concern has been the identification of abstractions and linguistic primitives for collective adaptation, location modelling, knowledge handling, and system interaction and aggregation.

Such work is always experimental and we have worked with a number of exploratory formalisms that are based on, or have taken inspiration from PEPA and SCEL, two languages that partners of the project have developed in the past years and that have proved very successful in modelling adaptive systems (SCEL) and in supporting quantitative analysis (PEPA). We have used four exploratory formalisms, STOCS, PALOMA, PEPA-S and Stochastic HYPE, with specific features that are each very interesting for CAS modelling and analysis. Through modelling a number of examples with these formalisms we are able to assess the impact of new primitives on CAS specification and verification. In order to ensure that we have a good foundation for comparison all formalisms have been applied to a concrete scenario inspired by the QUANTICOL bike-sharing case study.

Each of the exploratory languages has specific traits. One of the key features of STOCS is the use of attribute-based communication that is a valuable alternative to broadcast or binary synchronisation that appear to be inappropriate in CAS and fits well with the notions of *anonymity* and *dynamicity* of CASs. PALOMA, instead, stresses the role of locations as attributes of agents; their communication abilities depend on their location, through a *perception function* and only agents who enable the appropriate reception action have the capability to receive the message. In PEPA-S heterogeneous populations of indistinguishable agents operating on a set of locations are considered. PEPA-S aims at distilling and studying the set of interaction patterns that are typical of CASs. Like in PALOMA, in PEPA-S the ability of agents to communicate depends on their location. Stochastic HYPE aims at modelling three distinct types of behaviour: instantaneous events that happen as soon as specific conditions are met, stochastic events with durations drawn from exponential distributions and continuous behaviour described by ODEs over systems variables. Agents can be modelled individually or as populations with various types of communication between agents. This interaction can be influenced by the local state of the environment allowing for adaptation.

	Semantics	**Communication**	**Representation of Environment**	**Adaptation**
STOCS	4 CTMC semantics with different levels of abstraction	asynchronous within knowledge repository	within knowledge repository	through assessing and manipulating knowledge repository
PALOMA	2 CTMC semantics with different levels of abstraction + mean field approximation	synchronous message broadcast	perception function	limited state dependence through perception function
PEPA-S	population CTMC semantics + mean field approximation	shared actions and synchronous broadcast	perception function	limited state dependence through perception function
HYPE	hybrid semantics based on PDMP	shared actions and shared variables	flows, controllers, and event conditions	state dependent event conditions and rates

This exploratory work has considerably deepened our appreciation of the trade-offs between language expressiveness and scalable analysis and the choices involved in capturing adaptation and an environment. This provides a firm foundation for the development of CAS-SCEL in the second year of the project. Moreover, the formalisms are each interesting in their own right and have spawned several publications.

The research activities within WP4 have proceeded smoothly and there has been no major deviation from the initial work plan in Annex I. The resources allocated to the work package have been functional and necessary to the achievement of the results. In the first 12 months, the only active task of WP4 has been Task 4.1, concerned with the design of the language for CAS. We are now set to start working on language implementation (Task 4.2) and on design workflow (Task 4.3).

3.5 Work Package 5

The activities in Work Package 5 during the first year of the project have been primarily concerned with initial data-gathering activities regarding the case studies on smart public transportation (bus networks and bike sharing systems) and smart grids. Through this work we have been able to establish a critical validation of the quality of the information that is publicly available, and an analysis of the real data offered to us by project collaborators.

Figure 5: Screenshot from the live map at `https://web.barclayscyclehire.tfl.gov.uk/maps` providing live bike availability at London's Waterloo station.

During the first period we have developed particularly fruitful interaction with Lothian Buses, an Edinburgh-based company which operates a large bus network. We have obtained large sample data sets related to bus network structure and measurements related to the City of Edinburgh both through data available to the general public and confidential data from Lothian Buses. This data from the operator offers higher-quality information, consisting of detailed records of GPS locations, bus speeds, timestamps, and bus identifiers. With this data we have been able to carry out exploratory modelling studies (resulting in two papers accepted for publication) further cementing our relationship with Lothian Buses and establishing that the quantity and quality of the data is sufficient to calibrate and validate certain spatial models of bus networks.

For bike-sharing systems we focussed on publicly available data. Most systems offer web access to live information on the availability of bikes at parking stations (see Figure 5 for an example). These websites can be systematically queried to reconstruct real availability traces at any desired granularity. Some operators have also provided historical traces consisting of journey details, including start/end dates and source/destination stations. Using the publicly available datasets for the bike sharing system of the City of London as a prototypical example, our data analysis confirms that these measurements can be used for spatial models with an explicit representation of the network topology.

Models of smart grids can benefit from the availability of measurements and forecasts at the transmission level, offering aggregated information about energy production, consumption, and market prices at the national electricity-network scale. Load measurements to calibrate models at a smaller scale (i.e., neighbourhood or building level) are also available in the research community. These are also accompanied by network benchmarks consisting of prototypical layouts that have been extensively studied in the literature. Overall, the available data is sufficient for the QUANTICOL purposes, as demonstrated by a number of related papers already published. In the longer term, it will be possible to build large-scale models of adaptivity considering the short-term weather forecasts to drive adaptive control policies, and initial work has started in that direction (see Figure 6).

Another aspect of the work of this work package during the period has been concerned with identifying use-case requirements for building the QUANTICOL tool integration platform. An initial requirements-elicitation activity has highlighted a predominance of Java as the platform of choice for tool development by the project partners. This choice, however can still accommodate non-Java contributions, due to specific tool requirements or to the partners' expertise. Such an integration is possible, for instance, by exploiting a number of already available language bridging mechanisms such as Java Native Interfaces or Matlab's javabuilder. The requirements-elicitation has been successfully completed, as reported in Deliverable D5.1. The emergence of a consensus around Java as the platform of reference for tool development gives a solid basis on which to plan our future work on tools and their integration.

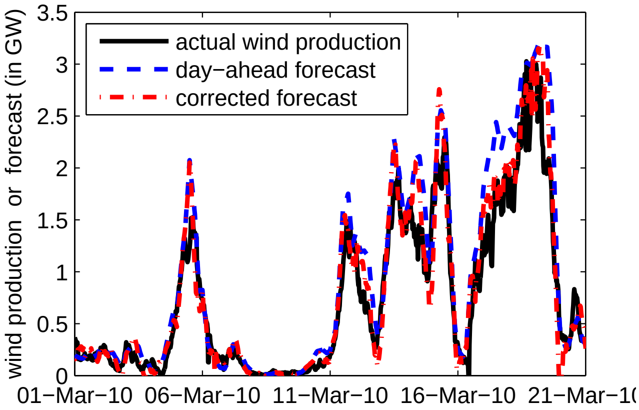


Figure 6: Wind forcast and production at the scale of UK. Typical sample of day-ahead forecast W^{WP} and forecast with linear correction W^{LC} versus actual wind power production (March 2010). Figure courtesy of *Impact of storage on the efficiency and prices in real-time electricity markets.* Nicolas Gast, Jean-Yves LeBoudec, Alexandre Proutière and Dan-Cristian Tomozei. In Proceedings of the Fourth International Conference on Future Energy Systems, pages 15–26. ACM, 2013.

Research in this work package has been carried out according to plans. There are no significant deviations from the description of work in Annex I. The use of resources is also in line with Annex I. Future work can proceed as planned, consolidating Tasks 5.1.a and 5.2.a and starting Java-centric tools-integration activities within Task 5.3.

4 Project Management

4.1 Management and Communication

The management of the project has been achieved through the work of the coordinator, in conjunction with the Management Board, which consists of site leaders and work package leaders. This group meets monthly by teleconference to monitor progress and discuss future plans.

There is a project wiki and mailing lists which are used for internal communication within the project. The wiki has been used extensively in the first year to share our appreciation of existing literature, via annotated bibliographies shared between project members. The wiki is also used as an early dissemination platform within the project where work in progress, technical reports and submitted papers can be shared with project partners for information and feedback. In addition meeting reports and minutes, for example of the monthly teleconference, are also made available via the wiki.

The management of the project has run smoothly during the first year and there were no problems to be resolved. However, we have had some change of partners as key members of the QUANTICOL team progressed their career by changing institution.

4.2 Amendments

There have been two amendments to the project necessitated by key members of the team changing institution. This was a sign of young researchers associated with the project advancing their careers:

Mirco Tribastone took up a senior lectureship at the University of Southampton on 1st September 2013. Dr Tribastone was the site leader at LMU, the natural amendment was for LMU to withdraw from the project and Southampton to join the project instead. In this way we were able to retain Dr Tribastone's expertise within the project.

Nicolas Gast had been employed as the principal research on the project at EPFL and on 1st February 2014 he took up a permanent position at INRIA Grenoble. Although Dr Gast was not the formal site leader at EPFL, he had been the key contact and was keen to maintain his involvement with the other project members. The EPFL PI, Prof Le Boudec, suggested that EPFL withdraw from the project, to be substituted by INRIA Grenoble. This has allowed the smooth continuation of the project. It also frees some resource, since Dr Gast's salary is now mostly covered by INRIA, to appoint a postdoc to work with him in Grenoble. Thus additional effort is now available to the project.

4.3 Project meetings

There have been three full project meetings during the first year of the project:

24–25th April 2013, Edinburgh — Project Kickoff Meeting This first meeting of the project was an opportunity for the project coordinator to welcome everyone to the project and discuss the work to be undertaken. One half day of the meeting was given over to presentations to members of the Advisory Board, and they helped shape our approach to the case studies, and our plans for dissemination.

2nd–3rd July 2013, Lausanne — Plenary Project Meeting This meeting was held jointly with the ASCENS project, which has some partners in common with QUANTICOL, allowing us to understand the complementary directions of the two projects with one half day of shared presentations. Additionally members of QUANTICOL presented their initial work to each other, discussed future directions and plans for collaboration.

10–11th February 2014, Pisa — Plenary Project Meeting This meeting served to review the work of the first year of the project and discuss the content of the first set of deliverables. A member of our Advisory Board, Prof Franco Zambonelli from the Unviersity of Modena, was present at this meeting, participating in discussions of the work completed and giving us advice on future directions. In the remainder of the meeting we set the agenda for the coming months.

Additionally there have been regular monthly teleconferences for the Management Board, comprised of representatives of all sites, to monitor the scientific progress of the project. These are documented and minuted on the project wiki.

Furthermore we held a technical workshop involving members of Work Packages 2 – 4 in Edinburgh, October 30th-31st 2013. The objective of the workshop was to share ideas and knowledge on topics related to spatial modelling and spatial logics. This informed the development of the work reported in Deliverables 2.1, 3.1 and 4.1.

In addition to the interactions with Advisory Board members mentioned above, we have held meetings with Advisory Board members, Stuart Lowrie and Bill Johnston, related to the smart transport case studies, as detailed in Section 4.8.2 below.

4.4 Project planning and status

The project has proceeded very smoothly during the first year with all work packages following the plan set out in Annex I. We anticipate that the second year of the project will similarly follow the work plan with little deviation.

Unfortunately due to the ongoing status of the amendments we are not able to access the NEF tool in reporting mode and submit the Form C. For that reason we have included the tables about the use of resources and direct costs here for information.

4.5 List of Scientific Publications in Months 1–12

1. Ezio Bartocci, Luca Bortolussi, Laura Nenzi, and Guido Sanguinetti. On the robustness of temporal properties for stochastic models. In Thao Dang and Carla Piazza, editors, *HSB*, volume 125 of *EPTCS*, pages 3–19, 2013. (⋆ *CNR/UEDIN/IMT collaboration* ⋆)

2. Roberto Bruni, Andrea Corradini, Fabio Gadducci, Alberto Lluch Lafuente, and Andrea Vandin. Modelling and analyzing adaptive self-assembly strategies with Maude. *Science of Computer Programming*, 2013. Available online 14 December 2013.

3. Luca Bortolussi, Rocco De Nicola, Nicolas Gast, Stephen Gilmore, Jane Hillston, Mieke Massink, and Mirco Tribastone. A quantitative approach to the design and analysis of collective adaptive systems. In *1st FoCAS Workshop on Fundamentals of Collective Systems*. Taormina, Sicily, Italy, September 2013. (⋆ *Multi-site collaboration* ⋆)

4. Luca Bortolussi and Richard A. Hayden. Bounds on the deviation of discrete-time Markov chains from their mean-field model. *Performance Evaluation*, 70(10):736–749, 2013. Proceedings of IFIP Performance 2013 Conference.

5. Luca Bortolussi and Roberta Lanciani. Model checking Markov population models by central limit approximation. In Kaustubh Joshi, Markus Siegle, Mariëlle Stoelinga, and Pedro R. D'Argenio, editors, *Quantitative Evaluation of Systems*, volume 8054 of *Lecture Notes in Computer Science*, pages 123–138. Springer Berlin Heidelberg, 2013. (⋆ *CNR/IMT collaboration* ⋆)

6. Luca Bortolussi, Diego Latella, and Mieke Massink. Stochastic process algebra and stability analysis of collective systems. In Rocco Nicola and Christine Julien, editors, *Coordination Models and Languages*, volume 7890 of *Lecture Notes in Computer Science*, pages 1–15. Springer Berlin Heidelberg, 2013.

7. Roberto Bruni, Alberto Lluch Lafuente, and Ugo Montanari. Constraint design rewriting. *Science of Computer Programming*, 2013. Available online 13 November 2013.

8. Luca Bortolussi and Guido Sanguinetti. Learning and designing stochastic processes from logical constraints. In Kaustubh Joshi, Markus Siegle, Mariëlle Stoelinga, and Pedro R. D'Argenio, editors, *Quantitative Evaluation of Systems*, volume 8054 of *Lecture Notes in Computer Science*, pages 89–105. Springer Berlin Heidelberg, 2013. (⋆ *CNR/UEDIN collaboration* ⋆)

9. Luca Bortolussi and Mirco Tribastone. Differential analysis of interacting automata with immediate actions. In *7th International Conference on Performance Evaluation Methodologies and Tools*, Torino, Italy, December 2013. (⋆ *CNR/SOTON collaboration* ⋆)

10. Vincenzo Ciancia. Interaction and observation: Categorical semantics of reactive systems through dialgebras. In Reiko Heckel and Stefan Milius, editors, *Algebra and Coalgebra in Computer Science*, volume 8089 of *Lecture Notes in Computer Science*, pages 110–125. Springer Berlin Heidelberg, 2013.

11. Anastasis Georgoulas, Jane Hillston, and Guido Sanguinetti. ABC-Fun: A probabilistic programming language for biology. In Ashutosh Gupta and Thomas A. Henzinger, editors, *Computational Methods in Systems Biology*, volume 8130 of *Lecture Notes in Computer Science*, pages 150–163. Springer Berlin Heidelberg, 2013.

12. Jane Hillston, Andrea Marin, Carla Piazza, and Sabina Rossi. Contextual lumpability. In *7th International Conference on Performance Evaluation Methodologies and Tools*, Torino, Italy, December 2013.

13. Alireza Pourranjbar and Jane Hillston. An aggregation technique for large-scale PEPA models with non-uniform populations. In *7th International Conference on Performance Evaluation Methodologies and Tools*, Torino, Italy, December 2013.

14. Stefano Sebastio and Andrea Vandin. MultiVeStA: Statistical model checking for discrete event simulators. In *7th International Conference on Performance Evaluation Methodologies and Tools*, Torino, Italy, December 2013. (⋆ *IMT/SOTON collaboration* ⋆)

15. Maurice H. ter Beek, Alberto Lluch Lafuente, and Marinella Petrocchi. Combining declarative and procedural views in the specification and analysis of product families. In *Proceedings of the 17th International Software Product Line Conference Co-located Workshops*, SPLC '13 Workshops, pages 10–17, New York, NY, USA, 2013. ACM.

16. Max Tschaikowski and Mirco Tribastone. Insensitivity to service-time distributions for fluid queueing models. In *7th International Conference on Performance Evaluation Methodologies and Tools*, Torino, Italy, December 2013.

17. Vashti Galpin. Hybrid semantics for Bio-PEPA. *Information and Computation*, 2014. Available online January 2014.

18. Diego Latella, Michele Loreti and Mieke Massink. On-the-fly Fast Mean-Field Model-Checking. In M. Abadi and A. Lluch Lafuente, editors, *Trustworthy Global Computing*, 4th International Symposium, TGC 2013, Buenos Aires, Argentina, August 30-31, 2013, Revised Selected Papers, volume 8358 of *Lecture Notes in Computer Science*, pages 297-314. Springer, 2014. (⋆ *CNR/IMT collaboration* ⋆)

19. Jane Hillston. Challenges for Quantitative Analysis of Collective Adaptive Systems. In M. Abadi and A. Lluch Lafuente, editors, *Trustworthy Global Computing*, 4th International Symposium, TGC 2013, Buenos Aires, Argentina, August 30-31, 2013, Revised Selected Papers, volume 8358 of *Lecture Notes in Computer Science*, pages 14-21. Springer, 2014.

4.6 QUANTICOL technical reports in months 1–12

1. D. Latella, M. Loreti and M. Massink. *On-the-fly PCTL Fast Mean-Field Model-Checking for Self-organising Coordination. Preliminary version.* QUANTICOL TR-QC-01-2013. Dec. 17, 2013.

2. M.H. ter Beek, S. Gnesi, and A. Fantechi. *Chaining available tools to support the modelling and analysis of a bike-sharing product line: An experience report.* QUANTICOL TR-QC-02-2013. Dec. 20, 2013.

3. M.H. ter Beek, S. Gnesi, and F. Mazzanti. *Model Checking Value-Passing Modal Specifications.* QUANTICOL TR-QC-03-2013. Dec. 20, 2013.

4. V. Ciancia, D. Latella, M. Massink. *Logics of Space and Time.* QUANTICOL TR-QC-01-2014. Jan. 08, 2014.

5. G. Iacobelli, M. Tribastone, A. Vandin. *Differential Ordinary Lumpability in Markovian Process Algebra.* QUANTICOL TR-QC-02-2014. Feb. 04, 2014.

6. D. Latella, M. Loreti, M. Massink, V. Senni. *Stochastically timed predicate-based communication primitives for autonomic computing — Full Paper.* QUANTICOL TR-QC-03-2014. Feb. 05, 2014.

7. R. Paškauskas, L. Bortolussi. *Multiscale Reductions of Mean Field and Stochastic Models.* QUANTICOL TR-QC-04-2014. Feb. 05, 2014.

8. V. Galpin, C. Feng, J. Hillston, M. Massink, M. Tribastone, M. Tschaikowski. *Review of time-based techniques for modelling space.* QUANTICOL TR-QC-05-2014. Apr. 08, 2014.

4.7 List of Dissemination Activities

4.7.1 Presentation of research results

- On June 3, 2013, Mieke Massink (CNR) gave a brief presentation of the QUANTICOL project at the 15th International Conference on Coordination Models (COORDINATION 2013) that took place in Florence as part of the 8th International Federated Conference on Distributed Computing Techniques (DisCoTec 2013). There were approximately 40 international delegates, mostly academic and mostly from the Formal Methods community.

- On June 22, 2013, Luca Bortolussi (CNR) gave an invited lecture about Fluid Model Checking techniques, partially developed within QUANTICOL, at the Bertinoro summer school on Formal Methods (`http://www.sti.uniurb.it/events/sfm13ds/`). There were approximately 30 people in the audience, predominantly PhD students coming from all over Europe.

- On June 25, 2013, Jane Hillston (UEDIN) gave a presentation of the QUANTICOL project to the Laboratory for Foundations of Computer Science lunchtime meeting. There were approximately 30 people in the audience, predominantly from the University of Edinburgh but several from other universities in Scotland.

- On 31st August, 2013, Jane Hillston (UEDIN) gave an invited talk at the 8th International Symposium on Trustworthy Global Computing (TGC 2013) in Buenos Aires, Argentina which was essentially about the QUANTICOL project. There were approximately 30 people in the academic audience from around the world.

- On October 16, 2013, Vincenzo Ciancia (CNR) gave a presentation which included information about the QUANTICOL project in the Dagstuhl Seminar 13422, "Nominal Computation Theory".

- On 10th February, 2014, Mirco Tribastone (SOTON) gave a seminar at the Dipartimento di Elettronica, Informazione, and Ingegneria of Politecnico of Milano, where he discussed some recent QUANTICOL results about the analysis of large-scale software systems[1].

4.7.2 Participation in FoCAS community events

- In June 2013, Stephen Gilmore (UEDIN) and Luca Bortolussi (CNR) attended the FoCAS coordination action in Barcelona. All FoCAS projects were represented at the meeting. There were 35 delegates, all academic.

- On 2nd September 2013, Mirco Tribastone (SOTON) gave a presentation about the QUANTICOL project at the *1st FoCAS workshop on the Fundamentals of Collective Adaptive Systems*, co-located with ECAL 2013, Taormina, Sicily, Italy. There were approximately 30 participants, some of whom were not related to FoCAS.

- On 7th November 2013, Vashti Galpin (UEDIN) took part in a panel on FoCAS on multi-disciplinary approaches for smart, green and integrated transport at ICT 2013 in Vilnius, Lithuania.

[1] `http://www.deib.polimi.it/eventi/dettaglio.php?&id_elemento=695&idlang=eng`

4.8 Engagement with other projects in FoCAS

- On May 15, 2013, Mieke Massink posted a brief description of QUANTICOL to the blog of the related EU-IP ASCENS project: `http://www.ascens-ist.eu/`.
- The QUANTICOL and ASCENS projects came together for a joint meeting hosted at EPFL in Lausanne, Switzerland, in July 2013.
- On 1st October 2013, Stephen Gilmore (UEDIN) and Mirco Tribastone (SOTON) attended the second project meeting of the CASSTING project, another FoCAS project, in Aalborg, Denmark. Stephen Gilmore gave a short presentation about the QUANTICOL project. There were 38 delegates at the meeting, including representatives from the industrial partners.
- On 14th February 2014, Jane Hillston, Allan Clark, Daniël Reijsbergen, and Stephen Gilmore (UEDIN) met members of the Smart Society FoCAS project including Michael Rovatsos to learn about each others' projects and learn about potential areas of collaboration.

4.8.1 Engagement with other projects and communities beyond FoCAS

- On July 17, 2013, Luca Bortolussi (CNR) gave an invited talk at the annual meeting of the APS INFORMS society in San José, Costa Rica, on fluid model checking. There were approximately 25 people in the audience.
- On 18th November 2013, Maurice ter Beek gave an invited presentation at the Copenhagen Meeting on Variability Analysis at the IT University of Copenhagen, Denmark. This was the kick-off meeting of the Danish project VARIETE (Variability in Portfolios of Dependable Systems).

4.8.2 Working meetings with owner and user communities

- On 2nd October 2013, Jane Hillston and Daniël Reijsbergen (UEDIN) met with Stuart Lowrie of the City of Edinburgh council to elicit requirements and identify transport-related problems and questions which were of genuine interest to the city.
- On October 21st 2013 Jane Hillston (UEDIN) met with Cecilia Oram from Sustrans, a UK charity whose objective is to encourage sustainable transport, with a primary focus on walking and cycling, but some interest also in buses.
- On 21st November 2013, Jane Hillston, Daniël Reijsbergen and Stephen Gilmore (UEDIN) held a working meeting with Bill Johnston of Lothian Buses.
- On 22nd November 2013 Mieke Massink (CNR) attended a meeting of FIAB-Pisa (Federazione Italiana Amici della Bicicletta — Italian Federation of Bicycle Friends).

4.8.3 Participation in trade shows and industry-focussed meetings

- On 5th November 2013, Stephen Gilmore and Daniël Reijsbergen from UEDIN presented the QUANTICOL project at Demofest 2013, an industry/academia meet-up in Glasgow. There were approximately 200 delegates at the event.

5 Deliverables and Milestones Table

Table 1. Deliverables

Del. no	Deliverable name	Version	WP no	Lead	Nature Beneficiary	Dissemination Level	Delivery date from Annex I	Actual/Forecast delivery date	Status	Comments
D1.1	Multiscale modelling informed by smart grids	1.0	1	EPFL/INRIA	R	PU	31/3/2014	31/3/2014	Submitted	
D2.1	A preliminary investigation of capturing spatial information for CAS	1.0	2	UEDIN	R	PU	31/3/2014	31/3/2014	Submitted	
D3.1	Foundations of scalable variation for stochastic logics	1.0	3	CNR	R	PU	31/3/2014	31/3/2014	Submitted	
D4.1	CAS-SCEL language design	1.0	4	IMT	R	PU	31/3/2014	31/3/2014	Submitted	
D5.1	Data validation and requirement for case studies	1.0	5	SOTON	R	PU	31/3/2014	31/3/2014	Submitted	
D6.1	Dissemination plan for the project	1.0	6	UEDIN	O	PU	31/3/2014	31/3/2014	Submitted	

Table 2. Milestones

Milestone no.	Milestone name	WP nos.	Lead beneficiary	Delivery date from Annex I	Achieved Yes/No	Actual/Forecast achievement date	Comments
MS1	Initial Design of the Language and Logic	WP3, WP4	CNR	31/3/2014	Yes	31/3/2014	Verification: D3.1, D4.1
MS2	Specification of the Quantitative Analysis Framework for the Language	WP1, WP2	INRIA	30/11/2014	Yes	31/3/2014	Verification: D1.1 D2.1
MS3	Requirements Analysis of the Case Studies	WP5	SOTON	31/3/2014	Yes	31/3/2014	Verification: D5.1
MS4	Language Extensions for Scalable and Spatial Analysis	WP1, WP2, WP4	UEDIN	31/12/2015	-	-	Verification: internal report T1.3, internal report T2.2, D4.2
MS5	CAS Tool Workbench, Design Methods and Case Studies	WP3, WP4, WP5	IMT	31/3/2017	-	-	Verification: D3.3, D4.3, D5.3

6 Explanation of the Use of Resources

TABLE 3.1:
Personnel, Subcontracting and Other Major Cost Items for Beneficiary UEDIN for Period

WP	*Item description*	*Amount*	*Explanations*
1,2,3,4,5	Personnel costs	95,929.17	Jane Hillston (PI) 0.96PM, Stephen Gilmore (Co-I), 0.96PM, 2 RAs, 1 PhD student and computer support 25.04PM
5	Other Direct Costs	2,233.21	Computing equipment for PI and RA
1,2,3,4,5	Other Direct Costs	1,585.08	Project kick-off meeting in Edinburgh 24-25th April 2013, catering and advisory board members travel expenses.
1,2,3,4	Other Direct Costs	940.30	Space workshop in Edinburgh 30th - 31st October 2013.
5	Other Direct Costs	229.14	Hosting Mirco Tribastone and Max Tschaikowski 1st November 2013.
5	Other Direct Costs	151.16	Daniël Reijsbergen interview expenses July 2013
1,2,3,4,5	Other Direct Costs	2,219.68	Three people to attend joint project meeting with ASCENS in Lausanne, July 2013.
3	Other Direct Costs	700.93	Daniël Reijsbergen presenting at Runtime Verification conference in Rennes, 24th - 27th September 2013.
2,4	Other Direct Costs	482.39	Support for visiting student from University of Trieste (Maddalena Rainieri, student of Luca Bortolussi), August 2013.
5	Other Direct Costs	53.06	Travel to Newcastle to meet potential collaborators
1	Other Direct Costs	1,056.64	Jane Hillston presenting at ValueTools conference in Torino, 9th-13th December 2013.
5	Other Direct Costs	263.31	Stephen Gilmore, QUANTICOL research collaboration visit to Southampton, 20th-21st March 2014.
1,2,3,4,5	Other Direct Costs	1,734.16	Four people and advisory board member to attend project meeting in Pisa, February 2014.
5	Other Direct Costs	70.59	*Traffic Flow Dynamics* book
6	Personnel costs	4,451.41	Jane Hillston (PI) 0.24PM, Stephen Gilmore (Co-I) 0.24PM, Daniël Reijsbergen 0.16PM
6	Other Direct Costs	32.20	Stephen Gilmore travel costs to DEMOfest in Glasgow, 6th November 2013
6	Other Direct Costs	609.39	Stephen Gilmore travel costs to FoCAS meeting in Barcelona, June 2013
6	Other Direct Costs	672.00	Stephen Gilmore travel costs to CASSTING meeting in Aalborg, 29th September - 2nd October 2013
6	Other Direct Costs	469.28	Vashti Galpin travel costs to attend FoCAS ICT panel in Villnius, 7-9th November 2013
7	Personnel costs	27,773.80	Jane Hillston (PI) 1.2PM, Portfolio Manager 1.2PM, Clerical support 4.2PM
7	Subcontracting	0	
Total direct costs as claimed on Form C		**141,656.90**	

TABLE 3.2:
Personnel, Subcontracting and Other Major Cost Items for Beneficiary CNR for Period

WP	*Item description*	*Amount*	*Explanations*
1,2,3,4,5	Personnel costs	76,271.02	Mieke Massink (PI) 3.01PM, Maurice ter Beek (Co-I) 1.45PM, Vincenzo Ciancia 2.33PM, Stefania Gnesi (Co-I) 1.65PM, Diego Latella (Co-I) 5.61PM
1,2,3,4,5	Other Direct Costs	1,843.36	Project kick-off meeting in Edinburgh 24-25th April 2013, travel expenses for six people.
2,3	Other Direct Costs	1,265.17	Travel to Space workshop in Edinburgh 28th - 31st October 2013 for four people.
1,2,3,4	Other Direct Costs	308.39	Travel expenses for Luca Bortolussi for collaborative research visit in Edinburgh, 6-13/06/2013.
3	Other Direct Costs	378.60	Mieke Massink presenting a paper at COORDINATION 2013 Conference, Florence, 3-5/06/2013.
1,2,3,4	Other Direct Costs	1,841.29	Four people to attend joint project meeting with ASCENS in Lausanne, 1-4/07/2013.
2,3,4	Other Direct Costs	44.60	Travel expenses for Diego Latella and Mieke Massink for collaborative meeting in Florence, 28/01/2014.
2,3	Other Direct Costs	17.40	Travel expenses for Vincenzo Ciancia for collaborative meeting in Florence 03/03/2014.
3	Other Direct Costs	835.18	Travel expenses for Maurice ter Beek and Stefania Gnesi for collaborative research visit to Southampton 3-5/03/2014.
6	Personnel costs	5,023.61	Mieke Massink (PI) 1.38PM,
6	Other Direct Costs	414.71	Maurice ter Beek, Trip to *Copenhagen Meeting on Variability Analysis 2013*, 17-19/11/2013.
6	Other Direct Costs	414.75	Travel costs for Luca Bortolussi to attend FoCAS meeting in Barcelona, 3-5/06/2013.
6	Other Direct Costs	314.47	Travel costs for Vincenzo Ciancia to attend Dagstuhl seminar 13422, Germany, 13-16/10/2013.
7	Subcontracting	0	
Total direct costs as claimed on Form C		**88,972.55**	

TABLE 3.3:
Personnel, Subcontracting and Other Major Cost Items for Beneficiary LMU for Period

WP	*Item description*	*Amount*	*Explanations*
6	Other Direct Costs	2,000	Travel of Mirco Tribastone to FoCAS meeting in Barcelona
7	Subcontracting	0	
Total direct costs as claimed on Form C		**2,000**	

TABLE 3.4: Personnel, Subcontracting and Other Major Cost Items for Beneficiary EPFL for Period			
WP	*Item description*	*Amount*	*Explanations*
1,5	Personnel costs	68,699.22	Nicolas Gast (Researcher) 9.75PM
6	Personnel costs	1,761.52	Nicolas Gast (Researcher) 0.25PM
7	Subcontracting	0	
Total direct costs as claimed on Form C		**70,460.74**	

TABLE 3.5: Personnel, Subcontracting and Other Major Cost Items for Beneficiary IMT for Period			
WP	*Item description*	*Amount*	*Explanations*
2,3,4,5	Personnel costs	82,684.00	Rocco De Nicola (PI) 3.25PM, Alberto Llurch Lafuente (Co-I) 2PM, Francesco Tiezzi (Co-I) 2PM, Valerio Senni (Co-I) 5PM, 2 PhD students 3PM
4	Other Direct Costs	671.87	Project kick-off meeting in Edinburgh 24-25th April 2013 travel expenses.
4	Other Direct Costs	118.85	Hosting visit by Luca Bortolussi, 29/09/2013-04/10/2013
4	Other Direct Costs	2,244.10	Seven people to attend joint project meeting with ASCENS in Lausanne, July 2013.
4	Other Direct Costs	396.31	Space workshop in Edinburgh 30th - 31st October 2013 travel expenses.
7	Subcontracting	0	
Total direct costs as claimed on Form C		**86,115.13**	

TABLE 3.6: Personnel, Subcontracting and Other Major Cost Items for Beneficiary SOTON for Period			
WP	*Item description*	*Amount*	*Explanations*
5	Personnel costs	49,389.09	Mirco Tribastone (PI) 0.1PM, 3 Postdocs 13PM
2	Other Direct Costs	1,448.80	Mirco Tribastone and Max Tschaikowski travel and subsistence costs to attend Space workshop in Edinburgh 29th October - 2nd November 2014.
1, 5	Other Direct Costs	2,047.75	Mirco Tribastone, Max Tschaikowski and Andrea Vandin travel, subsistence and registration costs to present at ValueTools Conference in Torino, Italy, 10th-13th December 2014.
1, 3, 5	Other Direct Costs	2,000.06	Mirco Tribastone, Max Tschaikowski and Giulio Iacobelli travel and subsistence costs to attend QUANTICOL plenary meeting in Pisa, Italy, 10th - 13th Feburary 2014.
3	Other Direct Costs	1,200.37	Mirco Tribastone travel, subsistence and registration costs to present at ICPE 2014, Dublin, Ireland, 23rd - 27th March.
6	Personnel costs	247.65	Mirco Tribastone (PI) 004.PM
6	Other Direct Costs	658.62	Mirco Tribastone travel and subsistence to attend FoCAS Workshop in Taormina, Italy, 1st-5th September 2014.
6	Other Direct Costs	660.01	Mirco Tribastone travel and subsistence to attend joint FoCAS meeting QUANTICOL/CASSTING, Aalborg, Denmark, 29th September - 2nd October 2014.
7	Subcontracting	0	
Total direct costs as claimed on Form C		**57,652.35**	

TABLE 3.7: Personnel, Subcontracting and Other Major Cost Items for Beneficiary INRIA for Period			
WP	*Item description*	*Amount*	*Explanations*
1,5	Personnel costs	10,184.33	Nicolas Gast (PI) 0.9PM, Bruno Gaujal (Co-I), 0.1PM
1	Other direct costs	798.54	Travel to project meeting in Pisa 10-13/02/2014
7	Subcontracting	0	
Total direct costs as claimed on Form C		**10,982.87**	

TABLE 4: PERSONNEL INVOLVED IN THE PROJECT				
Affiliation short name	Person name	Function or title	% of time on project	Remarks
UEDIN	Jane Hillston	Professor, PI	20%	
	Stephen Gilmore	Professor, Co-I	10%	
	Vashti Galpin	Research Fellow	50%	
	Daniël Reijsbergen	Research Assistant	100%	joined 01/08/2013
	Cheng Feng	PhD student	100%	joined 01/06/2013
	Allan Clark	Teaching Fellow	15%	zero cost
	Joanne Pennie	Portfolio Manager	10%	left 30/06/2013
	Joanne Mair	Portfolio Manager	10%	joined 01/07/2013
	Magdalena Mazurczak	Clerical Assistant	35%	left 19/04/2014
	Louise Redmonds	Clerical Assistant	0%	joined 20/04/2014
	Iain Rae	Computing Officer	10%	
CNR	Mieke Massink	Researcher, PI	36.58%	
	Stefania Gnesi	Director of Research, Co-I	13.75%	
	Diego Latella	Senior Researcher, Co-I	46.75%	
	Maurice ter Beek	Researcher, Co-I	12.42%	
	Vincenzo Ciancia	Researcher	19.42%	
	Luca Bortolussi	Associate Researcher	20.83%	zero cost
	Rytis Paskauskas	Postdoc	71.6%	zero cost
EPFL	Nicolas Gast	Researcher, Co-I	100%	joined INRIA 01/02/2014
IMT	Rocco De Nicola	Professor, PI	25%	
	Alberto Lluch Lafuente	Assistant Professor, Co-I	22%	
	Francesco Tiezzi	Assistant Professor, Co-I	11%	
	Valerio Senni	Assistant Professor, Co-I	29%	left 31/3/2014
	Farshad Shams	Postdoc	0%	joined 01/04/2014
	Michele Loreti	Assistant Professor	20%	zero cost
	Roberta Lanciani	PhD student	7%	
	Laura Nenzi	PhD student	7%	
	Marco Tinacci	PhD student	0%	joined 01/04/2014
SOTON	Mirco Tribastone	Senior Lecturer, PI	2%	
	Andrea Vandin	Postdoc	100%	joined 01/11/2013
	Giulio Iacobelli	Postdoc	50%	01/10/2013 – 31/3/2014
	Max Tschaikowski	Postdoc	66.7%	01/10/2013 – 31/3/2014
INRIA	Nicolas Gast	Researcher, PI	75%	from EPFL 01/02/2014
	Bruno Gaujal	Senior Researcher, Co-I	5%	joined 01/02/2014

7 Effort in the Period

	UEDIN	CNR	LMU	EPFL	IMT	SOTON	INRIA	Total
WP1 RTD	2.86	1.06	0	8.75	0	0	1.5	14.17
WP2 RTD	10.2	2.72	0	0	3	0	0	15.92
WP3 RTD	2.5	6.49	0	0	3	3	0	14.99
WP4 RTD	2.2	3.83	0	0	8	0	0	14.03
WP5 RTD	9.2	0	0	1	2.06	10.1	0	22.36
WP6 OTH	0.64	1.38	0	0.25	0	0.04	0	2.31
WP7 MGT	6.6	0	0	0	0	0	0	6.6
Total	34.2	15.48	0	10	16.06	13.14	1.5	90.38

8 Cumulated Effort since Beginning of the Project

	UEDIN	CNR	LMU	EPFL	IMT	SOTON	INRIA	Total
WP1 RTD	2.86	1.06	0	8.75	0	0	1.5	14.17
WP2 RTD	10.2	2.72	0	0	3	0	0	15.92
WP3 RTD	2.5	6.49	0	0	3	3	0	14.99
WP4 RTD	2.2	3.83	0	0	8	0	0	14.03
WP5 RTD	9.2	0	0	1	2.06	10.1	0	22.36
WP6 OTH	0.64	1.38	0	0.25	0	0.04	0	2.31
WP7 MGT	6.6	0	0	0	0	0	0	6.6
Total	34.2	15.48	0	10	16.06	13.14	1.5	90.38