INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Comète

Concurrence, Mobilité et Transactions

Futurs

THEME COM

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1. Team

Joint team with LIX (Laboratoire d'Informatique de l'Ecole Polytechnique) and CNRS.

Project-team Leader
Catuscia Palamidessi [Research Director (DR) INRIA, HdR]

Administrative assistant
Lydie Fontaine [Secretary (SAR) INRIA]

Staff members CNRS
Frank Valencia [Research Associate (CR) CNRS]

Associated researchers
Bernadette Charron-Bost [Research Associate (CR) CNRS, HdR]

Visitors
Robin Milner [Professor, University of Cambridge. One year visit.]
Diletta Romana Cacciagrano [Assistant Professor, University of Camerino, Italy. One month visit.]
Maria Grazia Vigliotti [PostDoc, Imperial College. Three months visit]
Cinzia Di Giusto [PhD student, University of Bologna, Italy. Four months visit.]

Ph. D. students
Kostas Chatzikokolakis [Allocataire École Polytechnique - Ministère]
Romain Beauxis [Allocataire Region Ile de France]
Sylvain Pradalier [Allocataire ENS Cachan. Co-supervised by Cosimo Laneve, University of Bologna, Italy]
Carlos Olarte [Allocataire INRIA - CORDIs]
Jesus Aranda [Co-supervised by Juan Francisco Diaz, Universidad del Valle, Colombia]

Post-doctoral fellows
Peng Wu [Post Doctorant INRIA till 31/8/2006. Post Doctorant CNRS since 1/10/2006]
Angelo Troina [Post Doctorant INRIA since 1/9/2006]

Student interns
Purnima Gupta [IIT, New Delhi. From 1/5/2006 till 31/7/2006]

2. Overall Objectives

2.1. Overall Objectives

The research of the Comète team focuses on the theoretical foundations of distributed and mobile systems. The project follows two main directions: the study, implementation and applications of the probabilistic π-calculus, a variant of the π-calculus, and the use of higher-order functional programming languages for distributed applications, in particular in the context of peer-to-peer systems.

Our main field of application are large-scale Distributed Mobile Systems (DMS) of computing devices of varying character providing diverse services. In this context, it is a daunting technical and scientific challenge to develop reasoning techniques which allow us to build systems guaranteeing that processes and data move in a secure, highly distributed network of devices which may individually exhibit failures but together work as a reliable, dependable system.

Formal *Specification and Verification* is of great help for system building and reasoning. The issue is to formally verifying whether a given system complies with a given specification typically expressed as temporal/spatial logic formulas, process expressions, or automata.

Model checking prevails in today's verification techniques. However, model checking usually needs a *finite-state* representation of systems, while most DMS are inherently open: there is no bound on the number of resources/devices that can be part of a system. In other words, many DMS's phenomena are best represented in models providing for unbounded or infinite systems. We consider the challenging problem of extending model checking techniques, possibly by combining them with deductive techniques, for the verification of DMS in *unbounded or (infinite)* scenarios.

Fault tolerance is a fundamental issue of DMS as they must often provide reliable services despite the occurrence of various types of failure. The use of specifications enriched with *stochastic* information and *probabilistic* reasoning provides a powerful mathematical tool for analyzing DMS that may exhibit failures. For example, stochastic information with probabilistic techniques can be used for specifying the rate at which faulty communication channels drop messages and for verifying message-delivery properties of the corresponding system. The probabilistic specification and verification of DMS is one of goals of Comète.

The highly distributed and mobile nature of the systems under consideration makes them more accessible and hence more vulnerable. *Security* is therefore crucial for these systems. The specification and verification of security properties has until now mainly addressed finite-state, deterministic processes (or protocols). We believe that more attention needs to be paid to infinite-state and probabilistic frameworks for the faithful modeling of features such as *nonce generation*, *cryptographic attacks*, and an *open number of participants*. Such features are prominently present in the DMS we are interested.

Our general goal is to provide rigorous theories and tools for the specification and verification of DMS. In particular, we shall deal with the following fundamental specific issues in the specification and verification of DMS: *Infinite (or Unbounded) Systems*, *Probabilistic Specifications* and *Specification and Verification of Security*. Our approach will involve the use of tools from Process Calculi, Constraint Technology and Probabilistic Methods. We shall introduce these tools before describing our project approach.

3. Scientific Foundations

3.1. Process calculi

Participants: Catuscia Palamidessi, Frank Valencia, Yuxin Deng, Jun Pang, Tom Chothia.

identification Calculi for expressing and formalizing the basic features of concurrent systems

Process calculi treat processes much like the λ-calculus treats computable functions. They provide a language in which the structure of *terms* represents the structure of processes together with an *operational semantics* to represent computational steps. For example, the term $P \parallel Q$, which is built from P and Q with the *constructor* $\parallel$, represents the process that results from the parallel execution of those represented by P and Q. An operational semantics may dictate that if P can evolve into P' in a computational step P' then $P \parallel Q$ can also evolve into $P' \parallel Q$ in a computational step.

An appealing feature of process calculi is their *algebraic* treatment of processes. The constructors are viewed as the *operators* of an algebraic theory whose equations and inequalities among terms relate process behavior. For instance, the construct $\parallel$ can be viewed as a commutative operator, hence the equation $P \parallel Q \equiv Q \parallel P$ states that the behavior of the two parallel compositions are the same. Because of this algebraic emphasis, these calculi are often referred to as *process algebras*.

Typically the operational semantics of process calculi interpret process term by using transitions (labeled or not) specifying its computational steps [5]. A labeled transition $P \xrightarrow{\mu} Q$ specifies that P performs μ and then behaves as Q. The relations $\xrightarrow{\mu}$ are defined according to the process calculus under consideration. In the next section we shall see those for the π-calculus [69], [70] which is perhaps the most prominent representative of calculi for mobile systems.

3.1.1. The π-calculus

In the early 90's Milner, Parrow, and Walker proposed the π-calculus [69], [70], a small paradigm for concurrency similar to CCS (the calculus for Communicating Systems, [68]) but enriched with constructs to support the the novel and powerful notion of link mobility. This proposal has had a tremendous impact on the community of Formal Methods for Concurrency, and stimulated or influenced research in other areas too, like for instance Security (cfr. the spi-calculus, [35]).

3.1.2. The asynchronous π-calculus

The π-calculus, like CCS, models communication by handshaking, namely as a *synchronous* interaction of both partners (rules COM and CLOSE). A few years after the introduction of the π-calculus, Honda and Tokoro [64] and, independently, Boudol [42], proposed a variant which models asynchronous communication instead. This variant has become known under the name of asynchronous π-calculus (π_a-calculus for short).

3.1.3. π versus π_a: the trade-off between expressiveness and distributed implementation

The π_a-calculus became quickly very popular, for several reasons:

- it is an elegant model of asynchronous communication, more abstract and more symmetric than previously proposed calculi for asynchronous communication,
- it has been "faithfully" implemented [81],
- it is simpler than the π-calculus, because it has fewer constructs, and yet
- it was believed to have the same expressive power as the π-calculus. This equivalence was not formally proved, but there were several hints in this direction: Milner's encoding of the lambda calculus in the π-calculus was re-done for π_a [42], it was shown that output prefix can be simulated [64], [42], and input-guarded choice as well [77]. Note that this justifies the more recent presentations of the π_a-calculus, which include input-guarded choice as an explicit operator [41], [37].

It was not only until some years later that the claim of equivalence was refuted: in [8] it was shown that the π-calculus is strictly more expressive than the π_a-calculus, in the sense that it is not possible to encode the first into the latter in a *uniform* way while preserving a *reasonable* semantics. Uniform essentially means homomorphic with respect to the parallel and the renaming operators, and reasonable means sensitive to the capability of achieving success in all possible computations. This result is based on the fact that in the π-calculus it is possible to define an algorithm for leader election in a symmetric network, while this cannot be done with the π_a-calculus. In [76] it was shown that the additional expressive power is due exactly to the mixed choice construct: choices with homogeneous guards (i.e. with input guards only, or output guards only) can be eliminated.

A consequence of the above results, however, is that the π-calculus cannot be implemented deterministically[1] in a fully distributed way. In fact, problems like the leader election in a symmetric network are known to have no deterministic solution in a distributed (asynchronous) system. The reason is that if processes follow a deterministic program then an adversary scheduler can always interleave the activities in such a way that the initial symmetry is never broken. See [83] for a proof of impossibility of this kind.

3.2. Specification logics

Participants: Catuscia Palamidessi, Frank Valencia.

identification Logics for expressing and formalizing properties of concurrent systems

In Comète we are interested in verifying whether a given process satisfies certain properties. These properties are often expressed in some logical formalism.

[1] The term "deterministic" here means "non-probabilistic".

3.2.1. Hennesy-Milner's modal logic.

A way of expressing process specifications is by using a process logic. One such a logic is the Hennesy-Milner's modal logic. The discriminating power of this logic with respect to a finite processes (i.e., recursion-free processes) coincides with strong bisimilarity (see [88]). That is, two finite processes are strongly bisimilar if and only if they satisfy the same formulas in the Hennessy-Milner's logic.

3.2.2. Temporal logics.

Hennesy-Milner's logic can express local properties such as "an action must happen next" but it cannot express long-term properties such as "an action eventually happens". This kind of property, which falls into the category of *liveness properties* (expressing that "something good eventually happens"), and also *safety properties* (expressing that "something bad never happens") have been found to be useful for reasoning about concurrent systems. The modal logics attempting to capture properties of the kind above are often referred to as *temporal-logics*.

Temporal logics were introduced into computer science by Pnueli [82] and thereafter proven to be a good basis for specification as well as for (automatic and machine-assisted) reasoning about concurrent systems. Temporal logics can be classified into linear and branching time logics. In the *linear* case at each moment there is only one possible future whilst in the *branching* case at each moment time may split into alternative futures.

3.3. Infinite systems

Participants: Catuscia Palamidessi, Frank Valencia.

This research is carried over in cooperation with Biorn Victor (Uppsala University), Vijay Saraswat (IBM, USA), and Stefan Dantchev (University of Durham, UK)

identification Constraints and process calculi approaches for proving properties of infinite-state systems

Verifying infinite systems is a particularly challenging and a relatively new area. Practical applications of this are still at a preliminary stage.

3.3.1. Constraints approach

Constraint-based verification [60], [55] has shown to be promising approach for infinite systems since a constraint formula is a natural symbolic representation of an infinite state set.

Open Constraint Satisfaction Problems have been recently introduced for specifying and solving constraints problems in highly distributed networks. In such a context typically there is no bound on the number of devices/resources that can be part of a given network. Algorithms for this kind of problems and their applications have been considered in [40], [43], [59]. Nevertheless little attention has been paid to the computational limits of these problems. I.e., studies establishing, for interesting classes of these problems are actually computationally solvable. This is certainly an issue when you allow unbounded number of resources as it is the case in DMS.

3.3.2. Process calculi approach

The study of expressive power of different forms of specifying infinite-behavior in Process Calculi is a recent line of research bringing understanding for infinite behavior of concurrent systems in terms of decidability.

Our work in [79] (see also [6], [89]), to our knowledge the first of this kind, deepened the understanding of process calculi for concurrent constraint programming by establishing an expressive power hierarchy of several temporal ccp languages which were proposed in the literature by other authors. These calculi, differ in their way of defining infinite behavior (i.e., replication or recursion) and the scope of variables (i.e., static or dynamic scope). In particular, it is shown that (1) recursive procedures with parameters can be encoded into parameterless recursive procedures with dynamic scoping, and vice-versa; (2) replication can be encoded

into parameterless recursive procedures with static scoping, and vice-versa; (3) the calculi from (1) are strictly more expressive than the calculi from (2). Moreover, it is shown that the behavioral equivalence for these calculi is undecidable for those from (1), but decidable for those from (2). Interestingly, the undecidability result holds even if the variables in the corresponding languages take values from a fixed finite domain whilst the decidability holds for arbitrary domains. The works [45], [46], [47] present similar results in the context of the calculus for communicating systems (CCS).

Both the expressive power hierarchy and decidability/undecidability results give theoretical distinctions among different ways of expressing infinite behavior. The above work, however, pay little attention to the existence efficient algorithms for the corresponding decidability questions or the existence of semi-decision procedures for the undecidable cases. These issues are fundamental if we wish to verify infinite-state process specifications, and hence we shall address it in this project.

3.4. Security

Participants: Catuscia Palamidessi, Frank Valencia, Kostas Chatzikokolakis.

identification Formalisms to express security properties and protocols and to verify them

Security protocols, also known as cryptographic protocols, are small concurrent programs designed to provide various security services across a distributed system. These goals include: authentication of agents and nodes, establishing session keys between nodes, ensuring secrecy, integrity, anonymity, non-repudiation, fairness, and so on. The challenge comes from the fact that we want to guarantee security of exchanges between participants using non-secure mediums, whose weaknesses can be exploited by malicious adversaries. In certain cases, like in the non-repudiation and fairness problems, we cannot even be sure that the participants are honest.

With the increasing degree of distribution and mobility of modern systems, and the increasing number of applications such as electronic commerce, electronic vote, etc, these protocols are becoming more and more used, and their correctness more and more crucial. Establishing the correctness of these protocols, however, is not an easy task; the difficulties arise from a number of considerations:

- The properties that they are supposed to ensure are extremely subtle; the precise meaning of a property is often a matter of debate and needs to be formally specified.
- The capabilities of adversaries (intruders, attackers, ...) are difficult to capture.
- By their nature security protocols involve a high degree of concurrency, which makes the analysis much more complicated.

Several formalisms have been proposed for the specification of the protocols and intruders, for the description of the security properties, and for proving correctness. For example, the Strand spaces [61], [48], the spi-calculus [35] and other process calculi [65], [85], [86], [38], formalisms based on linear logic [52], [67], on set-rewriting [66], [49], on rewriting logic [56], on tree automata [72], [62], and on set constraints [51].

4. Application Domains

4.1. Panorama

Keywords: *distributed applications*, *distributed systems*, *mobile systems*, *security*, *telecommunications*.

The foundational research of Comète (process calculi, communication and mobility, probabilistic studies, semantics and logics for concurrency, etc.) and the software tools we develop address the needs of many application domains. They are virtually applicable to any system or protocol made of distributed agents communicating by asynchronous messages, and where, possibly, the communication structure can change dynamically. Here we list the main domains of applications we envisage:

- Distributed and mobile systems: election algorithms, dynamic reconfiguration algorithms, fault tolerance algorithms;
- Databases: transaction protocols, distributed knowledge bases;
- Security protocols: authentication, electronic transactions;
- Telecommunications: mobile telephony, active network management, hot reconfigurations, feature interaction detection;

5. Software

5.1. A model checker for the probabilistic asynchronous π-calculus

In collaborations with Dave Parker and Marta Kwiatkowska, we are developing a model checker for the probabilistic asynchronous π-calculus. Case studies with Fair Exchange and MUTE, an anonymous peer-to-peer file sharing system, are in progress.

Technically we use MMC as a compiler to encode the probabilistic π-calculus into certain PRISM representation, which will then be verified against PCTL using PRISM. The transitional semantics defined in MMC can be reused to derive the symbolic transition graphs of a probabilistic process. The code for derivation will work as an add-on to MMC under XSB and invoke a graph traversal to enumerate all reachable nodes and transitions of the probabilistic process.

6. New Results

6.1. Semantics of probabilistic systems

One of the goals of Comète is to investigate the foundations of probabilistic calculi, and in particular the probabilistic asynchronous π-calculus described in Section 3.1.2.

6.1.1. Bisimulation semantics

In [14] we have studied a process calculus which combines both nondeterministic and probabilistic behavior in the style of Segala and Lynch's probabilistic automata. We have considered various strong and weak behavioral equivalences, and we have provided complete axiomatizations for finite-state processes, restricted to guarded definitions in case of the weak equivalences. We conjecture that in the general case of unguarded recursion the "natural" weak equivalences are undecidable.

This has been the first work, to our knowledge, to provide a complete axiomatization for weak equivalences in the presence of recursion and both nondeterministic and probabilistic choice.

6.1.2. Metrics

In systems that model quantitative processes, steps are associated with a given quantity, such as the probability that the step will happen or the resources (e.g. time or cost) needed to perform that step. The standard notion of bisimulation can be adapted to these systems by treating the quantities as labels, but this does not provide a robust relation, since quantities are matched only when they are identical. Processes that differ for a very small probability, for instance, would be considered just as different as processes that perform completely different actions. This is particularly relevant to security systems where specifications can be given as perfect, but impractical processes and other, practical processes are considered safe if they only differ from the specification with a negligible probability.

To find a more flexible way to differentiate processes, we have considered the notion of metric, which is a function that associates a real number (distance) with a pair of elements. In [22], we have studied metric semantic for a general framework that we call *Action-labeled Quantitative Transition Systems* (AQTS). This framework subsumes some other well-known quantitative systems such as probabilistic automata [87], reactive and generative models [90], and (a simplified version of) weighted automata [57], [71].

The metric semantics that we have investigated in [22] is based on rather sophisticated techniques. In particular, we needed to resort to the notion of Hutchinson distance.

Still in [22], we have considered two extended examples which show that our results apply to both probabilistic and weighted automata as special cases of AQTS. In particular, we have shown that the operators of the corresponding process algebras are non-expansive, which is the metric correspondent of the notion of congruence.

6.1.3. Probability and guards

In [31] we have proposed a probabilistic extension of the π-calculus whose main novelty is a probabilistic *mixed choice* operator, that is, a choice construct with a probability distribution on the branches, and where input and output actions can both occur as guards. We have developed the operational semantics of this calculus, and we have investigated its expressiveness. In particular, we have compared it with the sublanguage with the two *separate choices*, where input and output guards are not allowed together in the same choice construct. Our main result is that the separate choices can encode the mixed one. Further, we have showed that *input-guarded* choice can encode *output-guarded* choice and viceversa.

6.1.4. Parametric Probabilities

In [15] we have developed a model of Parametric Probabilistic Transition Systems, where probabilities associated with transitions may be parameters. We have showed how to find instances of the parameters that satisfy a given property and instances that either maximize or minimize the probability of reaching a certain state. As an application, we have modeled a probabilistic non–repudiation protocol with a Parametric Probabilistic Transition System. The theory we have developed allows us to find instances that maximize the probability that the protocol ends in a fair state (i.e. no participant has an advantage over the others).

6.2. A Framework for analyzing probabilistic protocols

Probabilistic security protocols involve *probabilistic choices* and are used for many purposes including signing contracts, sending certified email and protecting the anonymity of communication agents. Some probabilistic protocols rely on specific random primitives such as the *Oblivious Transfer* [84]. There are various examples in this category, notably the contract signing protocol in [58] and the privacy-preserving auction protocol in [73].

A large effort has been dedicated to the formal verification of security protocols, and several approaches based on process-calculi techniques have been proposed. However, in the particular case of probabilistic protocols, only few attempts of this kind have been made. One proposal of this kind is [36], which defines a probabilistic version of the noninterference property, and uses a probabilistic variant of CCS and of bisimulation to analyze protocols wrt this property.

In [50] and [12] we have developed a framework for analyzing probabilistic security protocols using a probabilistic extension of the π-calculus inspired by the work in [63], [80]. In order to express security properties in this calculus, we have extended the notion of testing equivalence [78] to the probabilistic setting. We have have applied these techniques to verify the Partial Secret Exchange, a protocol which uses a randomized primitive, the Oblivious Transfer, to achieve fairness of information exchange between two parties.

6.3. Theoretical and practical aspects of anonymity

The concept of anonymity comes into play in a wide range of situations, varying from voting and anonymous donations to postings on bulletin boards and sending mails.

The systems for ensuring anonymity often use random mechanisms which can be described probabilistically, while the agents' interest in performing the anonymous action may be totally unpredictable, irregular, and hence expressible only nondeterministically. In the past, formal definitions of the concept of anonymity have been investigated either in a totally nondeterministic framework, or in a purely probabilistic one. We have proposed a notion of anonymity which combines both probability and nondeterminism, and which is suitable for describing the most general situation in which both the systems and the user can have both probabilistic and nondeterministic behavior. We have also investigated the properties of the definition for the particular cases of purely nondeterministic users and purely probabilistic users.

We have investigated notions of strong anonymity in [39] and [27], [26]. One interesting feature of our approach is that in the purely probabilistic case, strong anonymity turns out to be independent from the probability distribution of the users. In [23], [19], [13] we have also investigated notions of weak anonymity. These are more realistic in the sense that they are more likely to be satisfied by the anonymity protocols used in practice.

Our notions of anonymity are defined in terms of observables for processes in the probabilistic π-calculus. As one of the goals of the project is to develop a model checker and other verification tools for this calculus, that will provide also a way to check automatically that the protocols satisfy the intended anonymity properties.

6.3.1. Information-Theoretic approaches

In [20] we have proposed a framework in which anonymity protocols are interpreted as particular kinds of channels, and the degree of anonymity provided by the protocol as the converse of the channel's capacity. We have investigated how the adversary can test the system to try to infer the user's identity, and we have studied how his probability of success depends on the characteristics of the channel. We have then illustrated how various notions of anonymity can be expressed in this framework, and showed the relation with some definitions of probabilistic anonymity in literature.

In [24], we have proposed a probabilistic process calculus to describe protocols for ensuring anonymity, and used the notion of relative entropy to measure the degree of anonymity that these protocols can guarantee. We have proved that the operators in the probabilistic process calculus are non-expansive, with respect to this measuring method. We have illustrated our approach by using the example of the Dining Cryptographers Problem.

6.4. Expressiveness of Concurrent formalisms

One of the most pressing questions in Concurrency is how the several languages and models that have been proposed compare to each other, and, in particular, which ones are the most suitable to capture the nature of concurrent and distributed computation. We have investigated the expressive power of various formalisms wrt to some of the key aspects of concurrency.

6.4.1. Synchronous vs Asynchronous Communication

One of the early results about the asynchronous π-calculus which significantly contributed to its popularity is the capability of encoding the output prefix of the (choiceless) π-calculus in a natural and elegant way. Encodings of this kind were proposed by Honda and Tokoro [64], by Nestmann [75] and (independently) by Boudol [42]. In [18], [11], we have investigated whether the above encodings preserve De Nicola and Hennessy's testing semantics. It turns out that, under some general conditions, no encoding of output prefix is able to preserve the must testing. This negative result is due to (a) the non atomicity of the sequences of steps which are necessary in the asynchronous π-calculus to mimic synchronous communication, and (b) testing semantics's sensitivity to divergence.

6.4.2. Replication vs Recursion

Another line of investigation has been represented by the comparison between various forms of recursion and replication in concurrent calculi. We have noted that the expressive power of recursion, and in particular whether or not it can be encoded by replication, depends critically on the notion of *scope* adopted for channel

names. In [30] we have surveyed various definitions of scope proposed in literature, and we have discussed their impact on the expressiveness of recursion.

6.4.3. Linearity vs Persistence

Finally, in [29] we have compared the expressive power of linear and persistent communication. We have consider four fragments of the π-calculus, corresponding to combinations of linearity/persistence also present in other frameworks such as Concurrent Constraint Programming and several calculi for security. The study is presented by providing (or proving the non-existence of) encodings among the fragments, a processes-as-formulae interpretation and a reduction from Minsky machines.

6.4.4. Distributed Agreement

In [28] we have systematized a collection of results on the expressiveness of process calculi obtained by the means of impossibility results in the field of distributed computing. In particular, we have focused on the *symmetric leader election problem* which allows to classify languages based on their capability of achieving a distributed agreement.

6.4.5. Fairness

In [17] we have defined fair computations in the π-calculus. We have followed Costa and Stirling's approach for CCS-like languages [53], [54] but exploited a more natural labeling method of process actions to filter out unfair process executions. The new labeling allowed us to prove all the significant properties of the original one, such as unicity, persistence and disappearance of labels. It also turned out that the labeled π-calculus is a conservative extension of the standard one. We contrasted the existing fair testing [44], [74] with those that naturally arise by imposing weak and strong fairness. This comparison provides the expressiveness of the various fair testing-based semantics and emphasizes the discriminating power of the one already proposed in the literature.

6.4.6. CCS with Replication and Grammars

In [34] we have explored the expressiveness of CCS with replication (CCSr) w.r.t. the existence of faithful encodings of models of computability *strictly less* expressive than Turing Machines. Namely, grammars of types 1,2 and 3 in the Chomsky Hierarchy. We have defined the language generated by a process as the set of finite maximal sequences of visible actions the process can perform. We have captured the notion of faithful encoding by restricting the co-domain of the encodings to a sub-class CCSr-w of CCSr processes. This restriction prevents language preserving encodings from adding non-terminating computations which do not correspond to the derivations of the encoded grammar. We have provided a language preserving encoding of type 3 grammars (Regular Languages) into CCSr-w. We then have showed that it is impossible to provide a language preserving encoding of type 2 grammars (Context Free Languages) into CCSr-w. We have showed that CCSr-w can generate languages which are not type 2. We finally have showed that the languages generated by CCSr-w processes are type 1 (Context Sensitive Languages). The impossibility result is rather surprising since it implies that the restriction of CCSr to CCSr-w processes renders an otherwise Turing powerful formalism into one that cannot encode Context-Free grammars.

6.5. A congruence format for name-passing calculi

In collaboration with the INRIA equipe Parsifal, in [33] we have defined a SOS-based framework to specify the transition systems of calculi with name-passing properties. This setting uses proof-theoretic tools to take care of some of the difficulties specific to name-binding and make them easier to handle in proofs. We have presented of a format ensures that open bisimilarity is a congruence for calculi specified within this framework, extending the well-known tyft/tyxt format to the case of name-binding and name-passing. We have applied this result to the π-calculus in both its late and early semantics.

6.6. Timed Concurrent Constraint Programming for Analyzing Biological Systems

Quantitative and partial information may help to better describe the behavior of many real-life systems. In the particular case of biological ones, the former is fundamental for description and experimentation purposes, and the latter allows to represent those facts that are not precisely known. Moreover, the dynamic nature of these systems makes the use of time in system descriptions a mandatory requirement. In [32] we have proposed ntcc, a timed concurrent constraint process calculus, as a convenient language to model biological systems. ntcc allows to describe both non-deterministic and asynchronous behavior, useful features for describing many scenarios such as unpredictable biological events. A crucial advantage of using ntcc is that interesting properties of biological models can be verified by appealing to its associated proof system. The advantages of following this approach are demonstrated by modelling the Sodium-Potassium pump, a cellular mechanism present in many live organisms.

7. Other Grants and Activities

7.1. Actions nationales

7.1.1. Project ACI Securité ROSSIGNOL

Participants: Kostas Chatzikokolakis, Catuscia Palamidessi.

The project ROSSIGNOL has started in 2003 and ended in 2006 and included the following participants:

- LIF. Responsible: D. Lugiez
- INRIA Futurs. Responsible: C. Palamidessi
- LSV. Responsible: F. Jacquemard
- VERIMAG.Responsible: Y. Lakhnech

ROSSIGNOL focuses on the foundations of Security Protocols. The goal of this project is the development of abstract models, simple enough to be used for the definition of a comprehensible semantics for the language of security properties. In particular, the project focuses on probabilistic models.

7.1.2. Project INRIA/ARC PRONOBIS

Participants: Romain Beauxis, Kostas Chatzikokolakis, Catuscia Palamidessi, Carlos Olarte.

The project PRONOBIS has started in 2006 and includes the following participants:

- ENS Cachan. Responsible: J. Gobault-Larrecq
- INRIA Futurs. Responsible: C. Palamidessi
- University of Birgmingham. Responsible: M. Kwiatkowska
- University of Verona. Responsible: R. Segala

The goal of the ProNobis project is to explore mixing probability and non-determinism in the semantics of transition systems, and also of programming languages. We plan to keep on eye on applications to typical computer related problems, in particular to problems stemming from security. Several interesting verification problems related to security involve proving that two processes are contextually equivalent. This usally uses notions such as bisimulation, which need to be better understood in a setting where probabilities, external non-determinism (choosing which action to fire in Markov decision processes), and internal non-determinism (where no visible action distinguishes between the various alternatives).

7.2. Actions internationales

7.2.1. DREI Equipes Associé PRINTEMPS

Participants: Kostas Chatzikokolakis, Tom Chothia, Yuxin Deng, Catuscia Palamidessi, Jun Pang.

The project has started in December 2005 and includes the following participants:

- INRIA Futurs. Responsible: C. Palamidessi
- Paris VII. Responsible: V. Danos
- McGill University. Responsible: P. Panangaden

PRINTEMPS focuses on the applications of Information Theory to security. We are particularly interested in studying the interactions between Concurrency and Information Theory.

7.2.2. Integrated Action Vallauris within the EGIDE/PAI PICASSO program

Participants: Catuscia Palamidessi, Frank Valencia, Kostas Chatzikokolakis.

The EGIDE/PAI program PICASSO aims at promoting the scientific and technological exchanges between France and Spain. The equip Comète is participating, within this program, to a project whose participants are:

- INRIA Futurs. Responsibles: Catuscia Palamidessi and Dale Miller
- Universidad Politécnica de Madrid. Responsibles: James Lipton and Manuel Hermenegildo

The main aims of our project, which has started in January 2005, are the integration of the approaches developed by the INRIA and the UPM teams to the analysis and implementation of Higher-Order Languages (both sequential and concurrent), coinductive techniques (with special emphasis on lazy features), and in the areas of code validation, proof carrying code and security.

8. Dissemination

8.1. Services to the Scientific Community

Note: In this section we include only the activities of the permanent internal members of Comète.

8.1.1. Organization of seminars

- Frank D. Valencia is the organizer of the Comète-Parsifal Seminar. This seminar takes place weekly at LIX, and it is meant as a forum where the members of Comète and Parsifal present their current works and exchange ideas. See http://www.lix.polytechnique.fr/comete/seminar/.

8.1.2. Editorial activity

- Catuscia Palamidessi is member of the Editorial Board of the journal on Mathematical Structures in Computer Science, published by the Cambridge University Press.
- Catuscia Palamidessi is member of the Editorial Board of the journal on Theory and Practice of Logic Programming, published by the Cambridge University Press.
- Catuscia Palamidessi is member of the Editorial Board of the Electronic Notes of Theoretical Computer Science, Elsevier Science.
- Frank D. Valencia is area editor (for the area of Concurrency) of the ALP Newsletter.

8.1.3. Steering Committees

- Catuscia Palamidessi is member of the council of the EATCS, the European Association on Theoretical Computer Science.

8.1.4. Organization of conferences

- Frank Valencia and Catuscia Palamidessi have been the organizers of the LIX colloquium on "Emerging Trends in Concurrency Theory" Palaiseau, France, November 2006. See http://www.lix.polytechnique.fr/comete/conferences/LIXColloquium2006/page/index.html.

8.1.5. Participation in program committees

Catuscia Palamidessi has been/is a member of the program committees of the following conferences:

- CiE 2008: Logic and Theory of Algorithms. Athens, Greece. June 2008.
- ESOP 2008. 17th European Symposium on Programming. (Part of ETAPS 2008.) Budapest, Hungary, March - April 2008.
- QEST'07. International Conference on Quantitative Evaluation of Systems. Edinburgh, UK, September 2007.
- CONCUR 2007. 18th International Conference on Concurrency Theory. Lisbon, Portugal, September 2007.
- FCT 2007. 16th International Symposium on Fundamentals of Computation Theory. Budapest, Hungary, August 2007.
- ESOP 2007. 16th European Symposium on Programming. (Part of ETAPS 2007.) Braga, Portugal, 24 March - 1 April, 2007.
- LPAR 2006. International Conference on Logic for Programming Artificial Intelligence and Reasoning. Phnom Penh, Cambodia, November 2006.
- CONCUR 2006. International Conference on Concurrency Theory. Bonn, Germany, August 2006.
- MFPS 2006. Twenty-second Conference on the Mathematical Foundations of Programming Semantics. University of Genova, Italy, May 2006.
- FOSSACS 2006. Foundations of Software Science and Computation Structures. (Part of ETAPS 2006.) Vienna, Austria, March 2006.

Catuscia Palamidessi has been/is a member of the program committees of the following workshops:

- FInCo 2007. Workshop on the Foundations of Interactive Computation. (Satellite event of ETAPS 2007). Braga, Portugal, March - April, 2007.
- EXPRESS'06. 12th International Workshop on Expressiveness in Concurrency. Bonn, Germany, August 2006.

8.1.6. Reviews

8.1.6.1. Reviews of journal papers:

ACM Transactions on Programming Languages, Theoretical Computer Science, Journal of Algebraic and Logic Programming, Information and Computation, IEEE Transactions on Parallel and Distributed Systems, Formal Aspects of Computing, Wireless Personal Communications, Journal of Universal Computer Science.

8.1.6.2. Reviews of conference papers:

LPAR 2006, CONCUR 2006, EXPRESS 2006, ESOP 2006, MFPS 2006, FOSSACS 2006, ICSE 2006, MIC 2006.

8.1.7. Best paper awards

- Tom Chothia has won the *Best Paper Award* at FORTE 2006, with the paper [21], which was mostly developed during 2005 while he was a postdoc in the Comète team.

8.2. Teaching

Note: In this section we include only the activities of the permanent internal members of Comète.

8.2.1. Postgraduate courses:

- Frank D. Valencia has given a course on Computability Theory at the PhD School of Informatics at Universidad del Valle, Colombia. January 2006.
- Catuscia Palamidessi is co-teaching (together with Jean-Jacques Lévy, Erik Gobault and James Leifer) the course "Concurrence" at the "Master Parisien de Recherche en Informatique" MPRI in Paris. Winter semester 2005-06.
- Catuscia Palamidessi has been co-teaching (together with Pierre-Louis Curien, Francesco Zappa-Nardelli, James Leifer and Roberto Amadio) the course "Concurrence" at the "Master Parisien de Recherche en Informatique" MPRI in Paris. Winter semester 2006-07.

8.2.2. Undergraduate courses:

- Frank D. Valencia has been a lecturer on "Concurrency Theory" at Universidad Javeriana de Cali. July 2006.

8.3. Advising

8.3.1. PhD students

The team Comète has supervised the following PhD students during 2006:

- Kostas Chatzikokolakis. Allocataire École Polytechnique - Ministère.
- Romain Beauxis. Allocataire Region Ile de France.
- Sylvain Pradalier. Allocataire ENS Cachan. Co-supervised by Cosimo Laneve, University of Bologna, Italy.
- Carlos Olarte. Allocataire INRIA - CORDIs.
- Jesus Aranda. Co-supervised by Juan Francisco Diaz, Universidad del Valle, Colombia.

8.3.2. Internships

The team Comète has supervised the following internship students during 2006:

- Purnima Gupta. IIT, New Delhi. From 1/5/2006 till 31/7/2006.

8.3.3. PhD defenses

Catuscia Palamidessi has been "rapporteur" at the following PhD thesis defenses during 2006:

- Jean Krivine. PhD thesis on *Reversible process algebra* defended on November 16, 2006. Advised by Jean-Jacques Lévy.

9. Bibliography

Major publications by the team in recent years

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Year Publications

Articles in refereed journals and book chapters

[11] D. CACCIAGRANO, F. CORRADINI, C. PALAMIDESSI. *Separation of synchronous and asynchronous communication via testing*, in "Theoretical Computer Science", to appear, 2006.

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