

CURRICULUM VITAE ET STUDIORUM

MARIO BRAVETTI

Personal Data

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Education and Qualifications

Feb 2002 PhD in Computer Science, from the consortium of Universities of Bologna, Padova and Venezia. Thesis Title: *“Specification and Analysis of Stochastic Real-Time Systems”*. Supervisor: Prof. Roberto Gorrieri. Reviewers: Prof. Joost-Pieter Katoen and Prof. Jane Hillston. Winner of the award for the two best theses in theoretical computer science in the year 2002, assigned by the Italian chapter of the European Association for Theoretical Computer Science.

Oct 2000 Habilitation for teaching Mathematics at Italian high schools.

Mar 1997 Master's degree in Computer Science, from the university of Bologna. Thesis Title: *“Un Linguaggio di Specifica Per Sistemi Semi-Markoviani Generalizzati”* (A Specification Language for Generalized Semi-Markovian Systems). Supervisor: Prof. Roberto Gorrieri. Co-Supervisor: Dott. Marco Bernardo. Mark: 110/110 cum laude.

Jul 1990 Scientific High School degree, from Liceo Scientifico “A. Oriani” of Ravenna.

Professional Activity

Oct 2002 - Assistant professor with tenure (ricercatore confermato and professore aggregato), in Computer Science, at the Faculty of Natural Mathematical and Physical Sciences of the University of Bologna, Master's Course in Computer Science located in Cesena.

Sep 2001 - Sep 2002 Postdoc (Assegnista di Ricerca) at the Department of Computer Science of the University of Bologna.

Nov 1997 - Oct 2001 PhD Student in Computer Science (XIII cycle) at the consortium of Universities of Bologna, Padova and Venezia.

Research Activity

The research activity concerns the following areas of computer science:

- Formal description techniques and software tools for modeling and analyzing distributed systems and protocols.
- Concurrency theory, Process Algebras, their axiomatizations and extensions.
- Stochastic processes with or without Markovian property, performance modeling and evaluation
- Service Oriented Computing, Web services, Orchestration and Choreography languages and related conformance issues.
- Architectural design and implementation of SOAP/RESTful Web Service based systems and Comet based rich internet applications.

In the following we present the list of publications and we describe in some detail the research activity.

List of Publications

Book Chapters

- [1] M. Bravetti, G. Zavattaro, “*Service Discovery based on Behavioural Contracts*”, in *International School on Formal Methods for the Design of Computer, Communication and Software Systems: Web Services*, SFM-09:WS, Revised Lectures, Bertinoro, Italy, June 1-6, 2009, to appear in LNCS, Springer.
- [2] M. Bravetti, “*Real Time and Stochastic Time*”, in *Formal Methods for the Design of Real-Time Systems, International School on Formal Methods for the Design of Computer, Communication and Software Systems*, SFM-RT 2004, Revised Lectures, Bertinoro, Italy, September 13-18, 2004, M. Bernardo and F. Corradini eds., LNCS 3185: 132-180, Springer, 2004.
- [3] M. Bravetti, P.R. D’Argenio, “*Tutte le algebre insieme: Concepts, Discussions and Relations of Stochastic Process Algebras with General Distributions*”, in *Validation of Stochastic Systems - A Guide to Current Research*, Christel Baier et al eds., LNCS 2925: 44-88, Springer, 2004
- [4] A. Aldini, M. Bravetti, A. Di Pierro, R. Gorrieri, C. Hankin, H. Wiklicky, “*Two Formal Approaches for Approximating Noninterference Properties*”, in *Foundations of Security Analysis and Design II*, R. Focardi and R. Gorrieri eds., LNCS 2946: 1-43, Springer, 2004

Articles on Scientific Journals

- [5] J.C.M. Baeten, M. Bravetti, “*A Ground-Complete Axiomatization of Finite-State Processes in a Generic Process Algebra*”, in *Mathematical Structures in Computer Science*, 18(6): 1057 - 1089, Cambridge University Press, 2008
- [6] M. Bravetti, G. Zavattaro, “*A Foundational Theory of Contracts for Multi-party Service Composition*”, in *Fundamenta Informaticae*, 89(4): 451 - 478, IOS Press, 2008
- [7] M. Bravetti, A. Casalboni, M. Núñez, I. Rodríguez “*From Theoretical e-Barter Models to Two Alternative Implementations Based on Web Services*”, in the *Journal of Universal Computer Science* 13(13): 2035-2075, Graz University of Technology, 2007
- [8] M. Bravetti, G. Zavattaro “*Service Oriented Computing from a Process Algebraic Perspective*”, in the *Journal of Logic and Algebraic Programming*, 70(1):3-14, Elsevier, 2007

- [9] M. Bravetti, R. Gorrieri, R. Lucchi, G. Zavattaro “*Quantitative Information in the Tuple Space Coordination Model*”, in *Theoretical Computer Science* 346(1):28-57, Elsevier, 2005
- [10] A. Aldini, M. Bravetti, R. Gorrieri, “*A Process-algebraic Approach for the Analysis of Probabilistic Non-interference*”, in *Journal of Computer Security* 12(2):191-245, IOS Press, 2004
- [11] M. Bravetti, A. Aldini, “*Discrete Time Generative-Reactive Probabilistic Processes with Different Advancing Speeds*”, in *Theoretical Computer Science* 290(1):355-406, Elsevier, 2003
- [12] M. Bernardo, M. Bravetti, “*Performance Measure Sensitive Congruences for Markovian Process Algebras*”, in *Theoretical Computer Science* 290(1):117-160, Elsevier, 2003
- [13] M. Bravetti, R. Gorrieri, “*Deciding and Axiomatizing Weak ST Bisimulation for a Process Algebra with Recursion and Action Refinement*”, in *ACM Transactions on Computational Logic* 3(4):465-520, ACM Press, 2002
- [14] M. Bravetti, R. Gorrieri, “*The Theory of Interactive Generalized Semi-Markov Processes*”, in *Theoretical Computer Science* 282(1):5-32, Elsevier, 2002

Technical Reports Accepted for Publication on Scientific Journals

- [15] M. Bravetti, G. Zavattaro, “*A Theory of Contracts for Strong Service Compliance*”, Technical Report UBLCS-2008-13, University of Bologna (Italy), June 2008 (full version of [24]), accepted on February 3rd, 2009 for publication on *Mathematical Structures in Computer Science*, Cambridge University Press.
- [16] M. Bravetti, G. Zavattaro, “*On the Expressive Power of Process Interruption and Compensation*”, Technical Report UBLCS-2008-15, University of Bologna (Italy), June 2008, accepted on February 16th, 2009 for publication on *Mathematical Structures in Computer Science*, Cambridge University Press.

Articles on Proceedings of Conferences/Workshops

- [17] M. Bravetti, I. Lanese, G. Zavattaro, “*Contract-Driven Implementation of Choreographies*”, in Proc. of the 4th Symp. on *Trustworthy Global Computing (TGC'08)*, LNCS 5474:1-18, Springer, Barcelona (Spain), November 2008
- [18] M. Bravetti, D. Latella, M. Loreti, M. Massink, G. Zavattaro, “*Combining Timed Coordination Primitives and Probabilistic Tuple Spaces*”, in Proc. of the 4th Symp. on *Trustworthy Global Computing (TGC 2008)*, LNCS 5474:52-68, Springer, Barcelona (Spain), November 2008.
- [19] M. Bravetti, G. Zavattaro, “*On the Expressive Power of Process Interruption and Compensation (Extended Abstract)*”, in Proc. of the 5th Int. workshop on *Web Services and Formal Methods (WS-FM 2008)*, to appear in LNCS, Springer, 2008.
- [20] M. Bravetti, G. Zavattaro, “*Contract Compliance and Choreography Conformance in the Presence of Message Queues*”, in Proc. of the 5th Int. workshop on *Web Services and Formal Methods (WS-FM 2008)*, to appear in LNCS, Springer, 2008.
- [21] M. Bravetti, G. Zavattaro, “*Foundational Aspects of Contract Compliance and Choreography Conformance*”, in Proc. of the workshop on *The Rise and Rise of the Declarative Datacentre*, K. Bhargavan, A. Gordon, T. Harris, P. Toft editors, Microsoft Research Technical Report MSR-TR-2008-61, pp. 11-14, Cambridge (UK), May 2008

- [22] M. Bravetti, S. Gilmore, C. Guidi, M. Tribastone “*Replicating Web Services for Scalability*”, In Proc. of *Trustworthy Global Computing, Third Symposium (TGC’07)*, LNCS 4912:204-221, Springer, Sophia-Antipolis (France), November 2007
- [23] M. Bravetti “*Expressing Priorities and External Probabilities in Process Algebra via Mixed Open/Closed Systems*”, In Proc. of the *14th International Workshop on Expressiveness in Concurrency (Express’07)*, ENTCS 194(2):31-57, Elsevier, Lisbon (Portugal), September 2007
- [24] M. Bravetti, G. Zavattaro “*A Theory for Strong Service Compliance*”, In Proc. of the *9th International Conference on Coordination Models and Languages (Coordination’07)*, LNCS 4467:96-112, Springer, Paphos (Cyprus), June 2007
- [25] M. Bravetti, G. Zavattaro “*Towards a Unifying Theory for Choreography Conformance and Contract Compliance*”, In Proc. of the *6th International Symposium on Software Composition (SC’07)*, LNCS 4829:34-50, Springer, Braga (Portugal), March 2007
- [26] M. Bravetti, G. Zavattaro “*Contract based Multi-party Service Composition*”, In Proc. of the *IPM International Symposium on Fundamentals of Software Engineering (FSEN’07)*, LNCS 4767:207-222, Springer, Tehran (Iran), April 2007
- [27] M. Bravetti “*Extensions of standard weak bisimulation machinery: finite-state general processes, refinable actions, maximal-progress and time*”, In Proc. of the *LIX colloquium Emerging Trends in Concurrency Theory*, ENTCS 209:83-106, Elsevier, Paris (France), November 2006
- [28] M. Bravetti, A. Casalboni, M. Núñez, I. Rodríguez “*From Theoretical E-barter Models to an Implementation Based on Web Services*”, in Proc. of the *IPM International Workshop on Foundations of Software Engineering (Theory and Practice) (FSEN’05)*, ENTCS 159:241-264, Elsevier, Tehran (Iran), October 2005.
- [29] M. Bravetti “*Stochastic and Real Time in Process Algebra: A Conceptual Overview*”, in Proc. of the meeting *Algebraic Process Calculi: The First Twenty Five Years and Beyond (PA’05)*, ENTCS 162:113-119, Elsevier, Bertinoro (Italy), August 2005
- [30] M. Bravetti, G. Zavattaro “*Service Oriented Computing: a new challenge for Process Algebras*”, in Proc. of the meeting *Algebraic Process Calculi: The First Twenty Five Years and Beyond (PA’05)*, ENTCS 162:121-125, Elsevier, Bertinoro (Italy), August 2005
- [31] M. Bravetti, H. Hermanns, J.-P. Katoen “*YMCA - Why Markov Chain Algebra? -*”, in Proc. of the meeting *Algebraic Process Calculi: The First Twenty Five Years and Beyond (PA’05)*, ENTCS 162:107-112, Elsevier, Bertinoro (Italy), August 2005
- [32] J.C.M. Baeten, M. Bravetti “*A generic process algebra*”, in Proc. of the meeting *Algebraic Process Calculi: The First Twenty Five Years and Beyond (PA’05)*, ENTCS 162:65-71, Elsevier, Bertinoro (Italy), August 2005
- [33] J.C.M. Baeten, M. Bravetti “*A Ground-Complete Axiomatization of Finite State Processes in Process Algebra*”, in Proc. of the *16th Int. Conf. on Concurrency Theory (CONCUR’05)*, LNCS 3653:248-262, Springer, San Francisco (CA, USA), August 2005
- [34] M. Bravetti, C. Guidi, R. Lucchi, G. Zavattaro, “*Supporting e-commerce systems formalization with choreography languages*”, in Proc. of the *20th ACM Symposium on Applied Computing (SAC’05), special track on E-Commerce Technologies*, pp. 831-835, ACM Press, Santa Fe (New Mexico, US), March 2005

- [35] M. Bravetti, R. Gorrieri, R. Lucchi, G. Zavattaro “*On the Expressiveness of Probabilistic and Prioritized Data-retrieval in Linda*”, in Proc. of the *2nd Int. Workshop on Security Issues in Coordination Models, Languages, and Systems (SecCo’04)*, ENTCS 128(5):39-53, Elsevier, London (UK), August 2004
- [36] M. Bravetti, N. Busi, R. Gorrieri, R. Lucchi, G. Zavattaro “*Security Issues in the Tuple-Space Coordination Model*”, in Proc. of the *2nd Int. Workshop on Formal Aspects in Security and Trust (FAST’04)*, in IFIP International Federation for Information Processing 173, Springer, Toulouse (France), August 2004
- [37] M. Bravetti, R. Lucchi, G. Zavattaro, R. Gorrieri “*Web Services for E-commerce: guaranteeing security access and quality of service*”, in Proc. of the *19th ACM Symposium on Applied Computing (SAC’04), special track on E-Commerce Technologies*, H. Haddad, A. Omicini, R.L. Wainwright and L.M. Liebrock eds., pp. 800-806, ACM Press, Nicosia (Cyprus), March 2004
- [38] M. Bravetti, R. Gorrieri, R. Lucchi, G. Zavattaro “*Probabilistic and Prioritized Data Retrieval in the Linda Coordination Model*”, in Proc. of the *6th Int. Conference on Coordination Models and Languages (COORDINATION 2004)*, R. De Nicola, G. Ferrari and G. Meredith eds., LNCS 2949:55-70, Springer, Pisa (Italy), February 2004
- [39] M. Bravetti, R. Gorrieri, R. Lucchi, G. Zavattaro “*Combining partitions in SecSpaces*”, in Proc. of the *Mefisto (formal methods for security and time) project final workshop*, ENTCS 99:31-47, Elsevier, Pisa (Italy), November 2003.
- [40] M. Bravetti, R. Gorrieri, R. Lucchi “*A formal approach for checking security properties in SecSpaces*”, in Proc. of the *1st Int. Workshop on Security Issues in Coordination Models, Languages, and Systems (SecCo’03)*, ENTCS 85(3), Elsevier, Eindhoven (The Netherlands), July 2003
- [41] M. Bravetti, “*An Integrated Approach for the Specification and Analysis of Stochastic Real-Time Systems*”, in Proc. of the *3rd Int. Workshop on Models for Time-Critical Systems (MTCS 2002)*, ENTCS 68(5), Elsevier, Brno (Czech Republic), August 2002
- [42] M. Bravetti, “*Revisiting Interactive Markov Chains*”, in Proc. of the *3rd Int. Workshop on Models for Time-Critical Systems (MTCS 2002)*, ENTCS 68(5), Elsevier, Brno (Czech Republic), August 2002
- [43] M. Bravetti, “*An Integrated Approach for the Specification and Analysis of Stochastic Real-Time Systems (Short Abstract)*”, in Proc. of the *2nd Int. Joint Workshop on Process Algebra and Performance Modelling, Probabilistic Methods in Verification (PAPM-PROBMIV 2002)*, LNCS 2399:209-210, Springer, Copenhagen (Denmark), July 2002
- [44] M. Bravetti, A. Aldini, “*Non-Determinism in Probabilistic Timed Systems with General Distributions*”, in Proc. of the *2nd Int. Workshop on Models for Time-Critical Systems (MTCS 2001)*, ENTCS 52.3, Elsevier, Aalborg (Denmark), August 2001
- [45] M. Bravetti, A. Aldini, “*Expressing Processes with Different Action Durations through Probabilities*”, in Proc. of the *Int. Joint Workshop on Process Algebra and Performance Modelling, Probabilistic Methods in Verification (PAPM-PROBMIV 2001)*, LNCS 2165:168-183, Springer, Aachen (Germany), September 2001
- [46] M. Bernardo, M. Bravetti, “*Reward Based Congruences: Can We Aggregate More?*”, in Proc. of the *Int. Joint Workshop on Process Algebra and Performance Modelling, Probabilistic Methods in Verification (PAPM-PROBMIV 2001)*, LNCS 2165:136-151, Springer, Aachen (Germany), September 2001
- [47] M. Bravetti, M. Bernardo, “*Compositional Asymmetric Cooperations for Process Algebras with Probabilities, Priorities, and Time*”, in Proc. of the *1st Int. Workshop on Models for Time-Critical Systems (MTCS 2000)*, ENTCS 39(3), Elsevier, State College (PA), 2000

- [48] A. Aldini, M. Bravetti, “*An Asynchronous Calculus for Generative-reactive Probabilistic Systems*”, in Proc. of the *8th Int. Workshop on Process Algebras and performance Modeling (PAPM 2000)*, J.D.P. Rolim et al. editors, pp. 591-605, Carleton Scientific, Geneva (Switzerland), July 2000
- [49] M. Bravetti, R. Gorrieri, “*A Complete Axiomatization for Observational Congruence of Prioritized Finite-State Behaviors*”, in Proc. of the *27th Int. Colloquium on Automata, Languages and Programming (ICALP 2000)*, U. Montanari, J.D.P. Rolim and E. Welzl editors, LNCS 1853:744-755, Springer, Geneva (Switzerland), July 2000
- [50] M. Bravetti, R. Gorrieri, “*Interactive Generalized Semi-Markov Processes*”, in Proc. of the *7th Int. Workshop on Process Algebras and Performance Modeling (PAPM '99)*, J. Hillston and M. Silva editors, pp. 83-98, Zaragoza (Spain), September 1999
- [51] M. Bravetti, R. Gorrieri, “*Axiomatizing ST Bisimulation for a Process Algebra with Recursion and Action Refinement (Extended Abstract)*”, in Proc. of the *6th Int. Workshop on Expressiveness in Concurrency (EXPRESS '99)*, ENTCS 27, Elsevier, Eindhoven (The Netherlands), August 1999
- [52] M. Bravetti, “*Towards the Integration of Real-Time and Probabilistic-Time Process Algebras*”, in Proc. of the *3rd European Research Seminar on Advances in Distributed Systems (ERSADS '99)*, Madeira Island (Portugal), April 1999
- [53] M. Bernardo, M. Bravetti, “*Functional and Performance Modeling and Analysis of Token Ring using EMPA*”, in Proc. of the *6th Italian Conf. on Theoretical Computer Science (ICTCS '98)*, P. Degano, U. Vaccaro and G. Pirillo editors, pp. 204-215, World Scientific, Prato (Italy), November 1998
- [54] M. Bravetti, M. Bernardo, R. Gorrieri, “*A Note on the Congruence Proof for Recursion in Markovian Bisimulation Equivalence*”, in Proc. of the *6th Int. Workshop on Process Algebras and Performance Modeling (PAPM '98)*, C. Priami editor, pp. 153-164, Nice (France), September 1998
- [55] M. Bravetti, M. Bernardo, R. Gorrieri, “*Towards Performance Evaluation with General Distributions in Process Algebras*”, in Proc. of the *9th Int. Conf. on Concurrency Theory (CONCUR '98)*, D. Sangiorgi and R. de Simone editors, LNCS 1466:405-422, Springer, Nice (France), September 1998
- [56] M. Bravetti, M. Bernardo, R. Gorrieri, “*From EMPA to GSMMPA: Allowing for General Distributions*”, in Proc. of the *5th Int. Workshop on Process Algebras and Performance Modeling (PAPM '97)*, E. Brinksma and A. Nymeyer editors, pp. 17-33, Enschede (The Netherlands), June 1997

Technical Reports Submitted for Publication on Scientific Journals

- [57] M. Bravetti, R. Gorrieri, “*A Uniform Approach for Expressing and Axiomatizing Maximal Progress and Different Kinds of Time in Process Algebra*”, Technical Report UBLCS-2008-14, University of Bologna (Italy), June 2008 (revision and extension of UBLCS-1999-18, July 1999 and of [49]), sottomesso a Theoretical Computer Science, Elsevier.

Other Significant Technical Reports

- [58] M. Bravetti, G. Zavattaro, “*Contract Compliance and Choreography Conformance in the Presence of Message Queues*”, May 2008, full version of [20].
- [59] M. Bravetti, “*Expressing Priorities, External Probabilities and Time in Process Algebra via Mixed Open/Closed Systems*”, Technical Report UBLCS-2007-18, University of Bologna (Italy), June 2007
- [60] M. Bravetti, G. Zavattaro, “*Towards a Unifying Theory for Choreography Conformance and Contract Compliance*”, Feb 2007, full version of [25].

- [61] M. Bravetti, R. Bernardo, “*Compositional Asymmetric Cooperations for Process Algebras with Probabilities, Priorities, and Time*”, Technical Report UBLCS-2000-01, University of Bologna (Italy), January 2000 (revised January 2001)
- [62] M. Bravetti, M. Bernardo, R. Gorrieri, “*GSMPA: A Core Calculus with Generally Distributed Durations*”, Technical Report UBLCS-98-06, University of Bologna (Italy), June 1998
- [63] M. Bravetti, M. Bernardo, R. Gorrieri, “*Generalized Semi-Markovian Process Algebra*”, Technical Report UBLCS-97-09, University of Bologna (Italy), October 1997

Theses

- [64] M. Bravetti, “*Un Linguaggio di Specifica per Sistemi Semi-Markoviani Generalizzati*”, Master Thesis, University of Bologna (Italy), March 1997
- [65] M. Bravetti, “*Specification and Analysis of Stochastic Real-Time Systems*”, PhD Thesis, University of Bologna (Italy), February 2002

Formal Methods for the Design of Distributed Systems and Protocols

Distributed systems and communication protocols have a leading role in modern society, due to the widespread usage of personal/mobile electronic communication devices, of computer networks, and global multimedia systems (WEB). The design and the correct functioning of these kind of systems is often based on coordination mechanisms with a high degree of complexity and the development of adequate theories for such mechanisms is essential to have actual correctness guarantees. Formal methods are assuming a more and more important role in the development process of these systems, especially because they offer a solid theoretical basis to verify their correctness and estimate their performance. Moreover, they provide tools for preliminary prototyping that can contribute to reduce the time of the engineering cycle, helping to detect design errors in the initial phases of development and avoiding costs of discovering them at later stages.

The research activity is mainly concerned with the usage of Process Algebras as a mathematical model that permits to develop unambiguous system and protocol specifications that can be built via graphical tools and that can be automatically analyzed via software tools. In particular it is possible to verify the correctness of such specifications with respect to a given set of requirements, make a preliminary analysis of the system performance in order to determine the design choices that lead to better results or (as, e.g., in the case of service oriented computing) exploit formal specifications even during software execution.

In particular the research activity concerns three main areas that range from a purely theoretical and foundational study on process algebra, to techniques for performance modeling and analysis in process algebra (in particular considering probabilistic time with general distributions and prioritized and probabilistic mechanisms), finally to issues concerning aspects more related to applicative domains such as the development of systems based on the Service Oriented Computing paradigm (in particular Web Services and representation of systems by means of choreographies and orchestrations).

Foundational Aspects of Process Algebras

The research activity concerns, besides some foundational results in classical process algebras (see [33, 32, 27, 5] where we extend the complete axiomatization of the Calculus of Communicating Systems - CCS to concurrent finite-state systems and where we present a general process algebra with which it is possible to express all other classical process algebras CCS, CSP e ACP), the study of techniques to express, by means of process algebras, systems with durational actions (represented by pairs of events of start and termination) [51, 13, 27], systems with prioritized mechanisms (for example originated by maximal progress in the presence of a notion of time) [49, 27, 57], systems where we explicitly represent time in a deterministic way (via discrete or continuous time) or in a probabilistic way (via either exponential distributions only or via general distributions) [42, 27, 57], systems with multilevel prioritized mechanisms and internal and

external probabilistic choices [23, 59]. It is important to observe that the significance of such a work relies not only in the fact of introducing new mechanisms in the classical process algebras (as, e.g., CCS) so to improve their expressivity, but, mainly, in the development of techniques that make it possible to do this while preserving the decidability results and complete axiomatization that hold true in the context of pure CCS.

Recently (in [16, 19]) we have also performed an expressivity analysis regarding the operators of interruption and exception handling in process algebra (important, for example, to represent transactional behaviours in Service Oriented Computing) by means of Turing Equivalence analysis under several conditions.

Modeling and Analysis of Stochastic Time and Real-time Systems

The main purpose of the research activity (that has been the main subject of the PhD thesis [65]) is the development of new techniques for the formal modeling and analysis of distributed systems and communication protocols with respect to timing aspects: verification of real-time properties and performance evaluation.

In particular the problem has been considered in its most generality: to represent systems with activities whose duration is probabilistic without any assumption on the distribution of probability (i.e. without doing the usual simplifying assumption of considering just exponential distributions). In this way the real-time constraints are expressible via probability distribution functions that associate probability greater than zero only to temporal values that are possible according to the constraints. The study of such a problem has led to determining the semantics needed to represent this kind of systems (solving a long-time open problem in the related scientific community): the ST semantics (where the actions are represented in the semantics as bound pairs of start and termination events) giving rise to a model with “clocks”, that are understood as essential to represent the behaviour of this kind of systems.

In particular, an important consequence of such a result, has been the possibility to develop and, notably, axiomatize *process algebras with generally (arbitrary) distributed actions* [64, 56, 63, 62, 55, 50, 14, 44, 3, 2], simply by interleaving (that in classical process algebra happens directly at the level of actions) of semi-actions of start and termination obtained by applying the ST semantics to the actions.

Representing both the real-time aspect and the probabilistic time aspect in a single language makes it possible to model concurrent systems in a more accurate way by expressing and analyzing the relationships among the two aspects of time. In particular, we can analyze a system by accounting for both the real-time and probabilistic time aspects, see [52, 41, 43]. By defining an adequate notion of *bisimulation based equivalence* that is a congruence with respect to all the operators of the language (see [54, 61] for the recursion operator), we can: verify the equivalence of systems by taking into consideration both the aspects of time, replace a part of a system with an equivalent one without changing the whole system behaviour and, finally, minimize the system representation. Besides, the possibility of performing combined analysis, it is possible to formally derive, from the initial specification of a concurrent system, a classical *real-time model* and a classical *performance model*, that are guaranteed to be consistent by construction (see [64, 63, 65]).

Moreover, an alternative methodology to the use of generalized semi-Markovian processes to realize the integration between the stochastic time and real-time approaches, has been introduced in [45, 11], where we present a process algebra based on simple discrete-time markov chains that is able of expressing both deterministic and probabilistic durations.

In order to reach a sufficient expressivity and be able to model a wide number of real systems, the stochastic process algebra must be endowed, besides the capability of expressing deterministic and probabilistic durations, of additional mechanisms that make it practically applicable. In [48, 11] a coordination mechanism has been developed, based on an integration of the classical generative and reactive probabilistic models, that makes it possible to express multilevel priorities and internal and external probabilistic choices. In [47, 61] such a generative-reactive synchronization mechanism has been used to modify the well-known stochastic process algebra EMPA, giving rise to $EMPA_{GR}$. As a consequence we have obtained the theoretical result of congruence of the Markovian equivalence that formerly did not hold: from a practical viewpoint this yields to the important capability of a compositional reduction of the state-space of a system specified with $EMPA_{GR}$.

In [39, 38, 35, 9, 18] we have shown that the generative-reactive model can be extended to deal with probabilistic/stochastic asynchronous matching based coordination models (tuple spaces).

Moreover, of great importance in order to evaluate the performance of a system, is the problem of how to express the performance measure of interest (e.g. the system throughput or the mean usage of a channel in a protocol). In [12, 46] such a problem is faced in the context of process algebras and the solution that is proposed is based on the usage of “rewards” to be associated with the actions that, in the algebraic specification, take part in the measure of interest. Many of the formal techniques that we have introduced are supported by the software tool TwoTowers developed in Bologna. This has allowed us to evaluate the potentiality of such techniques by developing several case studies: for instance the modeling and analysis of a router based on the probabilistic multipath routing [45, 11] and the evaluation and comparison of distributed algorithms for mutual exclusion [12].

Service Oriented Computing

The research activity (that has also led to the co-foundation, together with Gianluigi Zavattaro, of the international workshop on Web Services and Formal Methods - WS-FM, currently at its 6th edition) concerns the study of coordination and design techniques in Service Oriented Computing (SOC) and focuses on the study of the new theoretical problems arising in the context of such a paradigm. In particular, such new problems are often connected to the characteristic of “open endedness” (that is the open nature of the mechanism for service discovery and invocation) that the SOC paradigm takes to the extreme [8]: service invocation is based on a mechanism for publishing services on registries that are distributed on the network and for retrieving them, when needed, via matching between the information about the published services and the requirements on the service to be invoked. The information published on a registry for a given service may describe the service by means of a small behavioral specification called a “contract”: it represents the contract the service publisher makes with the service user, that is what is guaranteed about the way the service works. The characteristic of “open endedness” of the SOC paradigm makes it also problematic the engineering/design process of complex distributed systems based on services: the structure of the system may change (and be therefore established) at “run-time” based on available services that are retrieved on the network. In particular, the concepts of choreography and orchestration are extremely significant for the design and re-configuration of systems based on the SOC paradigm. The choreography is a high-level specification of the behavior of a set of services, while the orchestration is the specification (often executable via a so-called “engine”) of the behavior of a single service in terms of communication of other services. Often they are seen as subsequent phases of the engineering process where a unique global choreography gives rise to an orchestration for each service that is part of the choreography.

Formal methods play a preminent role in the context of the SOC paradigm and in particular of Web Services: a technology with a high industrial impact that is widely used for Business to Business applications. First of all, the usage of formal methods is extremely important for the unambiguous representation of specification languages that are described in natural language in standardization documents (for example languages BPEL4WS and WS-CDL for representing orchestrations and choreographies, respectively). Secondly, from a more applicative viewpoint, formal methods play an essential role in the specification of orchestration and choreography of systems (that, due to dynamic re-configuration, has a preminent role in a service system even at run-time) and in the representation/analysis of contracts.

The research activity concerns therefore a foundational study of the usage of formal methods, and in particular of process algebras, to represent contracts, orchestrations and choreographies. In particular (in [26, 25, 24, 6, 15, 60, 20, 58, 21, 19, 17, 1]) we concentrate on the problem of detecting, given a choreography that represents the desired behavior of a service system, a set of services on the network that, when executed together, realize the specified system. Supposing that every service publishes on the network (in a registry) a contract that represents its own behavior in an abstract way (a term of a process algebra), we study a refinement notion between contracts that satisfies the following key property: given a set of contracts that are reciprocally “compliant” (or a choreography) and considered a refined contract for each contract of the set, we want that the set of the obtained contracts are again reciprocally “compliant”, where for “compliant” we mean that the execution of the services they represent does not cause deadlocks or livelocks to arise. In

this way, given a choreography, service retrieval can be done by independently determining (hence in a parallel, compositional way) a service for each contract composing the choreography by simply applying the notion of refinement at the registries. More precisely, we have considered several notions of compliance: “classical” compliance based on synchronous communication with [25, 60] or without locations [26, 6, 1], strong compliance [24, 15] and compliance based on asynchronous communication using message queues [20, 58].

The developed approach is foundational in that, from the one side, it does not use a notion of refinement just by taking it from one of those that are well-known in the literature, but induces the relation directly from the desired property (independent refinement), studies the existence of a maximal/global relation (relating it with the characteristics of the language of the contracts/orchestrations and of the considered notion of compliance, normal or strong) by using co-induction and classifies it with respect to the existing ones: the resulting relation turns out to be coarser than the classical must-testing relation.

The developed theories and their extensions have been applied to Web Services [37] and to security [10, 4]. To this end we have also developed adequate coordination models [40, 36] and choreographies [34].

Moreover, in [28, 7] and several several laurea-degree theses, we have developed case studies on complex systems: architectural designs and implementations of SOAP/RESTful Web Service based systems, like, e.g., a distributed e-barter system, and Comet based rich Internet applications. The implementations are mostly based on Java standard and micro editions (for resource-constrained devices like PDAs and cellphones).

Participation in Research Projects

- 2006 - 2009** Project of Spanish Ministry of Science and Education *WEST* (WEb Services and Testing: foundations and applications).
- 2006 - 2008** Strategic Project of University of Bologna *CompReNDe* (Compositional and executable Representations of Nano Devices).
- 2005 - 2009** European Project FP6-2004-IST-FET Proactive: “*Software Engineering for Service-Oriented Overlay Computers (SENSORIA)*”.
- 2005 - 2006** Italian MIUR Project: “*Systems Biology: modellazione, linguaggi e analisi (Sybilla)*” (Systems Biology: modeling, languages and analysis).
- 2002 - 2003** Italian MIUR Project: “*Metodi Formali per la Sicurezza (MEFISTO)*” (Formal Methods for Security).
- 2000 - 2001** Italian MURST Project: “*Teoria della Concorrenza, Linguaggi di Ordine Superiore e Strutture di Tipi (TOSCA)*” (Theory of Concurrency, High Order Languages and Type Structures).
- 1998 - 1999** Italian MURST Project: “*Tecniche formali per la specifica, l’analisi, la verifica, la sintesi e la trasformazione di sistemi software*” (Formal techniques for the specification, the analysis, the verification, the synthesis and the transformation of software systems).

Activity as an Editor

- Editor of the special issues 70(2), 72(1) and 75(1) of *Journal of Logic and Algebraic Programming*, Elsevier, devoted to the meeting *Algebraic Process Calculi: The First Twenty Five Years and Beyond*, Aug 2005, Bertinoro - FC, Italy.
- Editor of the special issue 70(1) of *Journal of Logic and Algebraic Programming*, Elsevier, devoted to selected articles of the *1st International Workshop on Web Services and Formal Methods* (WS-FM 2004), Feb 2004, Pisa, Italy.

- Editor of volume 4184 of *Lecture Notes in Theoretical Computer Science*, (Springer): *Web Services and Formal Methods*, Proceedings of the 3rd International Workshop on Web Services and Formal Methods (WS-FM 2006), Sep 2006, Wien, Austria.
- Editor of volume 3670 of *Lecture Notes in Theoretical Computer Science*, (Springer): *Formal Techniques for Computer Systems and Business Processes*, Proceedings of the 2nd European Performance Engineering Workshop (EPEW 2005) and of the 2nd International Workshop on Web Services and Formal Methods (WS-FM 2005), Sep 2005, Versailles, France.
- Editor of volume 105 of *Electronic Notes in Theoretical Computer Science*, (Elsevier): *Proceedings of the 1st International Workshop on Web Services and Formal Methods* (WS-FM 2004), Feb 2004, Pisa, Italy.
- Editor of volume 99 of *Electronic Notes in Theoretical Computer Science*, (Elsevier): *Proceedings of the MEFISTO Project 2003, Formal Methods for Security and Time*.

Activity as a Reviewer

PhD Theses

- Member of the committee for the defense of the European PhD thesis of Mercedes Merayo (Mar 2009), at Complutense University of Madrid, Madrid (Spain).
- Reviewer of the PhD thesis of Gregorio Díaz Descalzo (Apr 2006) of University of Castilla-La Mancha (Spain).
- Member of the committee for the defense of the PhD thesis of Ismael Rodriguez (Jun 2004), at Complutense University of Madrid, Madrid (Spain).
- Member of the committee for the defense of the PhD thesis of Natalia Lopez (Mar 2003), at Complutense University of Madrid, Madrid (Spain).

Journals and Conferences

Mario Bravetti frequently performs reviews for several conferences and journals related to his research areas. Examples of journals for which he usually performs reviews are: *Science of Computer Programming* (Elsevier), *Information and Computation* (Academic Press), *Theoretical Computer Science* (Elsevier), *Fundamenta Informaticae* (IOS Press), *Journal of Logic and Algebraic Programming* (Elsevier), *Performance Evaluation* (Elsevier).

Activities Related to Visits Received

Jan 2005 - Feb 2005 He received a two months visit by Jos Baeten at the department of Computer Science, University of Bologna, during which the theories presented in [32, 33, 5] have been developed.

Activities Related to Conferences, Meetings and International Schools

Member of Steering Committees

- International Workshop on Web Services and Formal Methods, together with Wil van der Aalst (Eindhoven University of Technology, The Netherlands), Marlon Dumas (University of Tartu, Estonia), Jose Luiz Fiadeiro (University of Leicester, UK) and Gianluigi Zavattaro (University of Bologna, Italy).

Mario Bravetti is the *co-founder* of the workshop together with Gianluigi Zavattaro.

Preminent Roles in Conferences/Workshops

- CONCUR 2009: 20th International Conference on Concurrency Theory (PC co-chair e co-organizer)
- WS-BPI 2008: 1st Workshop on Web Services, Business Processes and Infrastructures (co-organizer)
- WS-FM 2006: 3rd International Workshop on Web Services and Formal Methods (PC co-chair)
- Algebraic Process Calculi: The First Twenty Five Years and Beyond, meeting held in 2005 (co-organizer)
- WS-FM 2005: 2nd International Workshop on Web Services and Formal Methods (PC co-chair)
- WS-FM 2004: 1st International Workshop on Web Services and Formal Methods (PC co-chair)
- ATPN 2004: 25th International Conference on Application and Theory of Petri Nets (satellite workshop and tutorial organizer)

Participation in Program Committees

- TISTO 2009: International Workshop on Timing and Stochasticity in Petri nets and other models of concurrency
- ICTAC 2009: 6th International Colloquium on Theoretical Aspects of Computing
- YR-SOC 2009: 4th European Young Researchers Workshop on Service-Oriented Computing
- FMOODS/FORTE 2009: IFIP international conference on Formal Techniques for Distributed Systems
- EPEW 2009: 5th European Performance Engineering Workshop
- MALLOW 2009 (AWESOME): Multi-Agent Logics, Languages, and Organisations Federated Workshops, Integrated Methodologies on Agents, Web-Services, and Ontologies
- FSEN 2009: IPM International Symposium on Fundamentals of Software Engineering
- CONCUR 2008: 19th International Conference on Concurrency Theory
- WS-FM 2008: 5th International Workshop on Web Services and Formal Methods
- FORTE 2008: 28th IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems
- ICSOC 2008: 6th International Conference on Service Oriented Computing
- EPEW 2008: 4th European Performance Engineering Workshop
- SCC 2008: IEEE International Conference on Services Computing
- SITIS 2008 (WITDS): The International Conference On Signal-Image Technology & Internet-Based Systems, Track on Web-Based Information Technologies & Distributed Systems
- WS-FM 2007: 4th International Workshop on Web Services and Formal Methods
- SAC 2007 (ECT): 22nd Annual ACM Symposium on Applied Computing, Special Track on E-Commerce Technologies
- FORTE 2007: 27th IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems

- EPEW 2007: 3rd European Performance Engineering Workshop
- FSEN 2007: IPM International Symposium on Fundamentals of Software Engineering
- SCC 2007: IEEE International Conference on Services Computing
- SITIS 2007 (WITDS): The International Conference On Signal-Image Technology & Internet-Based Systems, Track on Web-Based Information Technologies & Distributed Systems
- MALLOW 2007 (AWESOME): Multi-Agent Logics, Languages, and Organisations Federated Workshops, Integrated Methodologies on Agents, Web-Services, and Ontologies
- SAC 2006: 21th Annual ACM Symposium on Applied Computing, Special Track on E-Commerce Technologies
- FORTE 2006: 26th IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems
- EPEW 2006: 3rd European Performance Engineering Workshop
- QEST 2006: 3rd International Conference on the Quantitative Evaluation of Systems
- SAC 2005: 20th Annual ACM Symposium on Applied Computing, Special Track on E-Commerce Technologies
- IADIS International Conference on Applied Computing 2005
- PASM 2005: 2nd International Workshop on Practical Applications of Stochastic Modelling
- FORTE 2005: 25th IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems
- EPEW 2005: 2nd European Performance Engineering Workshop
- QEST 2005: 2nd International Conference on the Quantitative Evaluation of Systems
- SAC 2004: 19th Annual ACM Symposium on Applied Computing, Special Track on E-Commerce Technologies
- IADIS International Conference on Applied Computing 2004
- PASM 2004: 1st International Workshop on Practical Applications of Stochastic Modelling
- FORTE 2004: 24th IFIP WG 6.1 International Conference on Formal Techniques for Networked and Distributed Systems
- TheFormEMC 2004: 1st International Workshop on Theory Building and Formal Methods in Electronic/Mobile Commerce
- EPEW 2004: 1st European Performance Engineering Workshop

Tutorials, Invited Talks and Lectures

- Jul 2009** He will be lecturer on “A Testing-based Approach to Conformance in Service Composition” at the 5th TAROT Summer School on Software Testing, Palace-Castle Magalia, Las Navas del Marqués, Ávila (Spain).
- Jul 2009** He will be invited speaker at the 3rd International Workshop on Verification and Evaluation of Computer and Communication Systems (VeCoS 2009), Rabat (Morocco).
- Sep 2008** He is invited to give a talk at the meeting on Calculi for Service Oriented Computing, Lucca (Italy).
- Sep 2008** He is invited speaker at the 5th International Workshop on Web Services and Formal Methods (WS-FM 2008), Milano (Italy).
- May 2008** He is invited to give a talk at the meeting on the Rise and Rise of the Declarative Datacentre (R2D2), Microsoft Research, Cambridge (UK).
- Feb 2008** He gives a talk at the meeting Web Services, Business Processes and Infrastructures (WS-BPI 2008), London (UK).
- Oct 2007** He is invited to give a lecture on “Foundational aspects of contract compliance and choreography conformance” at the International PhD School in Theory and Practice of Business Process Execution and Service Orientation (BPESO), Copenhagen (Denmark).
- Nov 2006** He is invited to give a talk at the meeting Colloquium on Emerging Trends in Concurrency Theory, Paris (France)
- Sep 2004** He is invited to give a lecture on “Real Time and Stochastic Time” at the 4th Int. School on Formal Methods for the Design of Computer, Communication and Software Systems: Real Time (SFM-04: RT), Bertinoro - FC (Italy)
- Sep 2004** He is invited to give a tutorial on “Time in Process Algebra: A Conceptual Overview” at the *1st Int. Conference on the Quantitative Evaluation of Systems (QEST 2004)*, Enschede (The Netherlands)
- Jul 2003** He is invited to give a talk at the meeting *Process Algebra: Open Problems and Future Directions*, Bertinoro - FC (Italy)
- May 2003** He is invited to give a talk on [65] at the meeting *Dagstuhl Seminar on Probabilistic Methods in Verification and Planning*, Dagstuhl (Germany).
- Dec 2002** He is invited to give a talk on [3] at the meeting *Validation of Stochastic Systems (VOSS)*, Dagstuhl (Germany).
- Sep 2001** He is invited to give a tutorial on “Expressivity and Usability Issues in Stochastic Process Algebra” at the *Int. Multiconference on Measurement, Modelling and Evaluation of Computer-Communication Systems*, Aachen (Germany).
- Jul 2001** He is invited to give a lecture on “Stochastic Time” at the 1st Int. School on Formal Methods for the Design of Computer, Communication and Software Systems: Process Algebras (SFM-01: PA).
- May 2000** He is invited to give a talk on [55, 52, 14] at the *Dagstuhl seminar on Probabilistic Methods in Verification*, Dagstuhl (Germany).

Teaching Activity

Scientific Coordination and Organization of Teaching Programs

Oct 2006 - May 2007 Teaching Program TECNICO INFORMATICO (IT person) for unemployed undergraduates financed by the European Community (3rd objective - ESF year 2006), held at Centro Provinciale di Formazione Professionale of Ravenna, 500 theoretical/practical hours of which 225 of stage in companies.

Oct 2005 - May 2006 Teaching Program TECNICO INFORMATICO (IT person) for unemployed undergraduates financed by the European Community (3rd objective - ESF year 2005), held at Centro Provinciale di Formazione Professionale of Ravenna, 500 theoretical/practical hours of which 225 of stage in companies.

Jun 2004 - Apr 2005 Teaching Program E-DEVELOPER for unemployed undergraduates financed by the European Community (3rd objective - ESF year 2004), held at Centro Provinciale di Formazione Professionale of Ravenna, 700 theoretical/practical hours of which 250 of stage in companies.

Undergraduate/Master Courses at University

From Academic Year 2002/03 to present time Holder of course on Web Technologies/Internet at Corso di Laurea in Scienze dell'Informazione located in Cesena, University of Bologna (12 credits).

From Academic Year 1997/1998 to 2003/04 Teaches formal languages and automata theory within the course on theoretical computer science, holder Prof. Roberto Gorrieri, at Corso di Laurea in Scienze dell'Informazione located in Cesena, University of Bologna.

Academic Year 2000/2001 Teaches advanced usage of Microsoft Word e Microsoft Excel within the course on Theory and Applications of Computers (holder Prof. Alessandro Amoroso) at Corso di Laurea in Scienze Ambientali located in Ravenna, University of Bologna.

Industry Related Master Courses at University

Apr 2004 Teaches "Ipermedia on the Web" at the (industry related) first level master program in "Multimedia Technology e Applications" at the Centro di Ricerche e studi per l'Informatica Applicata alla Didattica (CRIAD) of the University of Bologna.

Supervision of Master Theses

Mario Bravetti has been supervisor of more than 20 master theses at the degree programs in computer science of the Faculty of Sciences of the University of Bologna, mostly on topics concerning the development of SOAP/RESTful Web Service based systems and Comet based rich Internet applications with web technologies based on Java standard and micro editions (for resource-constrained devices like PDAs and cellphones).