AutoMathA Workshop on
Developments and New Tracks in Trace Theory
Cremona, Italy, 9-11 October 2008
Final Report

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1 Summary

DNTTT ’08 was a 3-days workshop providing the opportunity to assess and exchange the recent scientific advances of the theory of traces (or partially commutative computation). This extension to formal language and automata theory offers much potential value for modelling and analyzing distributed and parallel systems. The meeting focused on algorithmic, algebraic, and logical aspects of the theory, as well as on models for analysis and synthesis of distributed systems.

The organizing and scientific committee included: Stefano Crespi Reghizzi (DEI, Politecnico di Milano), Dietrich Kuske (Institut für Informatik, Universität Leipzig), and Anca Muscholl (LaBRI, Université Bordeaux 1).

Local organization was provided by Paola Spoletini (DSCPI, Università dell’Insubria) and by Claudia Nuccio (Dipartimento di Matematica, Politecnico di Milano).

After the workshop approval by ESF, a web page was set up at:
`http://tracetheory.elet.polimi.it/scope.html`.
Invitations were sent to relevant scientists and most of them accepted. Moreover, a call for presentations was issued, and proposals for presentations were evaluated and a final list established.

Invited presentations had 45 minutes and submitted contributions had 30 minutes. Since the workshop does not publish the proceedings, some presentations discussed work in progress, while others concerned recently published results.

The participation was very representative of on-going research on Trace Theory, but also included persons doing research in neighboring fields. Senior and junior scientists, as well as PhD students attended. The 37 attendants came, in order of numerosity, from Italy, Germany, France, Poland, India, and UK.

Presentation slides have been collected and made available on the web page.

The panel discussion raised a list of open problems, to be made available to the scientific community on the web page.

The intense and lively atmosphere of the workshop was profitable for scientific exchange, and offered an opportunity for comparing on-going research on trace theory, and for fostering future scientific collaborations in this area, maybe as a second workshop on advances in trace theory.

The meeting was hosted by Politecnico di Milano on its campus at Cremona.

2 Scientific Content

The following description of the research area covered by the workshop is taken from the web page `http://tracetheory.elet.polimi.it/program.html`

> Computing systems can be seen nowadays as highly distributed and concurrent entities, that interact in various ways ranging from shared data to message exchange. Applications that need to be developed for such systems are particularly complex and reasoning about their correctness is a very challenging issue. Being able to apply formal methods for validating properties of such applications and systems is not merely of theoretical interest, but also a crucial goal in developing industrial critical systems of high quality and performance.
>
> Coping with concurrency on a rigorous sound basis is only possible if an appropriate formal model is available, that is rich enough for modelling purposes and sufficiently simple for providing a flexible framework for mathematical reasoning. Various models have been proposed for concurrent systems, let us just mention Petri nets, event structures, process algebras, or Milner-Hoares theory of communicating sequential systems. In the late seventies Mazurkiewicz proposed the notion of traces as an intuitive and mathematically elegant abstraction of concurrency. The underlying notion of partial commutations proved to be a very natural concept, that had been already considered in combinatorics by Cartier and Foata (1969), as well as in computer science in the area of parallel program schemata by Keller (1973). The theory of Mazurkiewicz traces is a particularly appealing framework, since it employs techniques and tackles problems from quite diverse areas including formal language theory, combinatorics, graph theory, algebra, logic, and the theory of concurrent and parallel systems. In all these areas the theory of traces has led to interesting problems and significant results, and The Book of Traces (1995) gives an excellent overview of the results obtained until the mid nineties.
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> In recent years, Mazurkiewicz trace theory has spread towards various other areas, continuing to be a rich source of powerful methods and of new challenging problems. Some of these offsprings are described next.
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> *Message sequence charts and synthesis of communicating automata*
> Communicating finite-state machines, or equivalently, FIFO channel systems or message passing automata, are the most basic model for concurrent peers that cooperate via asynchronous message pass- ing using unbounded buffers. Compared with other models of true concurrency, like Petri nets for instance, these machines are computationally much harder, actually Turing equivalent. Channel systems are the basis of the standard ITU notation SDL (norm Z.100). Their syntactic counterpart are message sequence charts (ITU norm Z.120), a standard that is widely used

in the design of protocols. Various results about the expressivity of these formalisms and the decidability of model-checking problems have been obtained by exploiting their connection with Mazurkiewicz traces. Trace theory is for instance the building brick in showing the equivalence of different specification formalisms under some natural assumptions on the channel scheduling policy.

Synthesis and control

Control problems arise in open environments, where a system is required to behave in a desired way, no matter how the environment acts. Control problems can be also viewed as games between a system and its environment, where being able to compute a winning strategy amounts to synthesize a controller that enforces the system to behave as specified. Whereas the control of sequential (finite-state) systems is meanwhile both well-understood and tractable, the case of distributed systems is more challenging (undecidable in the general case). Several restricted models for distributed games have been considered, and various decidability results and open problems are known. Trace theory plays again a fundamental role, since several game models are based on asynchronous automata, which are the standard model of distributed automaton associated with trace languages.

Concurrent temporal logics

Temporal logics for traces have been developed in the linear-time framework (i.e., formulas express properties of single distributed executions). As it turned out, the local logics are algorithmically more appealing than global ones. The investigations concentrate on two aspects: the search for a simple set of modularities that allow to capture the whole of first-order logic and methods for handling large sets of modularities efficiently. While the former problem has been solved by the results of Diekert and Gastin, the latter is still flourishing. In the light of the results on distributed games, it is a hard problem to come up with a branching time and local temporal logic that has the nice features of logics like CTL or CTL? . Furthermore, the transfer of insights from the trace setting into more applied scenarios like MSCs is not completed. Equations and word membership problems Partial commutation, the feature that separates free monoids from trace monoids, has been investigated in algebra independently from the development in computer science. The work on the solvability of equations in monoids (e.g., partially commutative inverse monoids, graph products) rejoins these two directions with surprising connections to Petri nets. The algorithms for deciding word membership have been investigated from the beginning, by Bertoni, Goldwurm and Sabbadini. Recently some research on more efficient solutions has focused on specific classes of languages, like star-free, local or languages corresponding to well-nested cycles.

Quantitative aspects

It is not just interesting to ask whether a particular word is accepted by a finite automaton, but also to know the number of different ways it can be accepted. This question developed into the theory of weighted automata and formal power series. Some of the cornerstones of trace theory have been analyzed in this light and some of the results on rational formal power series have been transferred into the trace setting, but much is left to be done, e.g., almost nothing is known about algebraic series in partially commuting variables. So far, the relation to probabilistic and timed systems remains to be explored in depth.

3 Assessment of the results and impact of the event on the future directions

The talks presented at this workshop covered a very wide range of topics, all related to the theory of Mazurkiewicz traces. With non-trivial overlap, they can be grouped as follows:

Application in group and monoid theory. The talks by Diekert and by Lohrey proved that techniques from trace theory can be applied to algorithmic questions in combinatorial group theory. Since the solvability of equations is central in this theory, also the investigations by Klunder & Stawikowska and of Breveglieri et al. lead into that direction.

Formal languages. Several very diverse approaches have been presented in this field. Kufleitner's ideas on Eilenberg's theorem for trace languages closes a gap in the transfer of classical language theory to traces, it can serve as starting point of further such developments. A related question was considered by Pin who investigated the relation between the partially commutative closure of a language and its algebraic properties. Ochmanski and Jolkowska presented classical ideas on trace languages. Kirsten's presentation on the star problem reminded all of us of his contribution to this long-standing open problem and in particular of the remaining (or at least next) cases that should be tackled. The talks by Droste and by Meinecke presented the advances in the theory of quantitative trace languages modeled after Schützenberger's and Eilenberg's approach via formal power series. This approach is also seen in the work of Bertoni & Radicioni on the speed up of traces.

Application for distributed systems. The original idea of Mazurkiewicz to use free partially commutative monoids to describe the behavior of distributed systems motivated the work by Morin on shared memory systems. It is also visible in current work on message sequence charts as presented by Muscholl, by Mukund, and by Kumar. Several presentations took a local view on traces, i.e., asked what single processes can detect or control about the whole system. Kuske dealt with local temporal logics and their verifaction algorithms, Gastin presented useful notions of local liveness and fairness, Mukund considered a local notion of testing and also Zeitoun's presentation of distributed games falls into this category.

Practical applications. Crespi-Reghizzi explained how practical real-live problems in code optimization by compilers lead to interesting and difficult problems on traces. Sabadini et al. presented a formalism for the specification of nets of automata. Breveglieri & Goldwurm considered the theoretically solved problem of the recognition of regular trace language from a practical point of view.

These presentations gave a rather complete overview of current trends in trace theory. Most of the results are part of ongoing research programmes, which proves that the area of trace theory is active and alive. This is also witnessed by the active participation of many young researchers. In particular the list of open problems (that is currently set up) will focus further developments.

Several participants expressed the opinion that the event should have a follow-up, possibly as a second workshop.

4 Final programme of the meeting

Developments and New Tracks in Trace Theory
Cremona, Italy, 9-11 October 2008

	October 9	**October 10**		**October 11**
9:30-10:15	Volker Diekert: Partially commutative inverse monoids	Paul Gastin: Characterizations of local safety and local liveness for traces	**9:30-10:15**	Ingmar Meinecke: Weighted distributed systems and their logics
10:15-10:45	Barbara Klunder, Krystyna Stawikowska: Word languages from trace viewpoint	Madhavan Mukund: Local testing for HMSC specifications	**10:15-11:00**	Daniel Kirsten: Star and star height problems for trace monoids
10:45-11:15	COFFEE BREAK		**11:00-11:30**	COFFEE BREAK
11:15-12:00	Manfred Droste: Weighted trace automata	Anca Muscholl: Algorithms for communicating systems	**11:30-12:15**	Stefano Crespi Reghizzi, Simone Campanoni: Traces of control-flow graphs
12:00-12:45	Dietrich Kuske: Which local temporal logics are tractable?	Marc Zeitoun: Distributed games and control	**12:15-12:45**	K. Narayan Kumar: Model checking time-constrained HMSCs
12:45	LUNCH		**12:45**	LUNCH
14:00-14:45	Edward Ochmanski: Lights and Darks of the Star-Free Star	Luca Breveglieri, Massimiliano Goldwurm: Algorithm for recognition of regular trace languages		
14:45-15:15	Markus Lohrey: Decision problems in graph groups	A. Cano Gomez, Giovanna Guaiana, Jean-Eric Pin: When does partial commutative closure preserve regularity?		
15:15-15:45	Manfred Kufleitner: A new algebraic framework for recognizable trace languages	Alberto Bertoni, Roberto Radicioni: Approximation of the mean speedup in trace monoids and random generation of traces		
15:45-16:15	COFFEE BREAK			
16:15-16:45	Rémi Morin: Partial order semantics of shared-memory systems	Luca Breveglieri, Alessandra Cherubini, Claudia Nuccio, Emanuele Rodaro: NP-completeness of the alphabetical satisfiability problem for trace equations		
16:45-17:15	Joanna Jolkowska: Traceability and Concurrent Fairness in Petri Nets	Nicoletta Sabadini, L.De Francesco Albasini, R. Walters: CospanSpan(Graphs): a compositional model for reconfigurable automata nets		
17:15-18:15		Panel Discussion		
20:15		SOCIAL DINNER		

5 Speakers

1. Luca Breveglieri, Politecnico di Milano, Italy (invited)
2. Stefano Crespi Reghizzi, Politecnico di Milano, Italy (invited)
3. Volker Diekert, Universität Stuttgart, Germany (invited)
4. Manfred Droste, Universität Leipzig, Germany (invited)
5. Paul Gastin, École Normale Supérieure de Cachan, France (invited)
6. Joanna Jolkwska, N. Copernicus University, Poland (contributing)
7. Daniel Kirsten, Universität Leipzig, Germany (invited)
8. Manfred Kufleitner, Universität Stuttgart, Germany (contributing)
9. K. Narayan Kumar, Chennai Mathematical Institute, India (contributing)
10. Dietrich Kuske, Universität Leipzig, Germany (invited)
11. Markus Lohrey, Universität Leipzig, Germany (contributing)
12. Ingmar Meinecke, Universität Leipzig, Germany (invited)
13. Lukasz Mikulski, N. Copernicus University, Poland (contributing)
14. Rémi Morin, Université de la Méditerranée, France (contributing)
15. Madhavan Mukund, Chennai Mathematical Institute, India (contributing)
16. Anca Muscholl, Universitè Bordeaux, France (invited)
17. Claudia Nuccio, Politecnico di Milano, Italy (contributing)
18. Edward Ochmanski, N. Copernicus University, Poland (invited)
19. Jean-Eric Pin, Université Paris Diderot, France (contributing)
20. Roberto Radicioni, Università degli Studi di Milano, Italy (contributing)
21. Nicoletta Sabadini, Università dell'Insubria, Italy (contributing)
22. Robert Walters, Università dell'Insubria, Italy (contributing)
23. Marc Zeitoun, Université Bordeaux, France (invited)

6 Participants

1. Alberto Bertoni, Università degli Studi di Milano, Italy
2. Alessandra Cherubini, Politecnico di Milano, Italy
3. Carlo A. Furia, Politecnico di Milano, Italy
4. Massimiliano Goldwurm, Università degli Studi di Milano, Italy

5. Giovanna Guaiana, Université de Rouen, France
6. Violetta Lonati, Università degli Studi di Milano, Italy
7. Giovanni Pighizzini, Università degli Studi di Milano, Italy
8. Matteo Pradella, Politecnico di Milano, Italy
9. Emanuele Rodaro, Università dell'Insubria, Italy
10. Pierluigi San Pietro, Politecnico di Milano, Italy
11. Pawel Sobocinski, University of Southampton, U.K.
12. Paola Spoletini, Università dell'Insubria, Italy
13. Michele Tartara, Politecnico di Milano, Italy
14. Massimo Tisi, Politecnico di Milano, Italy