Preface

Hybrid systems are interacting networks of digital and continuous systems. Hybrid systems arise throughout business and industry in areas such as interactive distributed simulation, traffic control, plant process control, military command and control, aircraft and robot design, and path planning. Three of the fundamental problems that hybrid systems theory should address are: How to model physical and information systems as hybrid systems; how to verify that their behavior satisfies program or performance specifications; how to extract from performance specifications for a network of physical systems and their simulation models digital control programs which will force the network to obey its performance specification. This rapidly developing area is at the interface of control, engineering and computer science. Methods under development are extensions of those from diverse areas such as program verification, concurrent and distributed processes, logic programming, logics of programs, discrete event simulation, calculus of variations, optimization, differential geometry, Lie algebras, automata theory, dynamical systems, etc.

When the first LNCS volume *Hybrid Systems* was published in 1993, the effect was to focus the attention of researchers worldwide on developing theory and engineering tools applicable to hybrid systems in which continuous processes interact with digital programs in real time. At the time of publication of this fifth volume, there is general agreement that this is an important area in which mathematics, control engineering, and computer science can be fruitfully combined. There are now hybrid system sections in many engineering and computer science international meetings, hybrid systems research groups in many universities and industrial laboratories, and also other excellent series of hybrid systems conferences.

The impetus for this volume was the Fifth International Hybrid Systems Workshop held in Notre Dame, Indiana, USA, September 11-13, 1997. Previous Hybrid Systems Workshops have taken place at MSI/Cornell (June 10-12, 1991), the Technical University Lyngby, Denmark (October 19-21, 1992), MSI/Cornell (October 28-30, 1994), DIMACS/SYCON Rutgers (October 22-25, 1995), and MSI/Cornell (October 12-14, 1996). The four volumes arising from these workshops were: *Hybrid Systems*, Springer-Verlag LNCS **736** (1991 and 1992 workshops); *Hybrid Systems II*, Springer-Verlag LNCS **999** (1994 workshop); *Hybrid Systems III*, Springer-Verlag LNCS **1066** (1995 workshop); and *Hybrid Systems IV*, Springer-Verlag LNCS **1273** (1996 workshop). All papers were fully refereed and selected from those submitted in a call subsequent to the Fifth International Hybrid Systems Workshop.

Here are brief summaries of the papers which have been included.

- Chen and Hanisch present a method for synthesizing hybrid feedback policies based on predicate invariance over the hybrid state space of the system.
- Chutinan and Krogh develop the machinery for constructing approximating automata for continuous systems where the continuous dynamics are

defined by convex polytopes in the space of derivatives of continuous space trajectories.

- Davoren proposes the propositional modal $\mu-$calculus – which subsumes most known temporal and modal propositional logics – as a broad logical framework for the formal analysis and verification of hybrid systems. Over transition system models equipped with a topological or metric structure, the logic can express continuity properties of transition relations and metric tolerance properties such as "being within distance ϵ" of a set of states, thus allowing formal verification of robustness and stability properties of hybrid dynamical systems.
- De Schutter and De Moor extend the Extended Linear Complementary Problem algorithms previously used for discrete event systems to analyze some classes of hybrid systems. Their case study is of a traffic-light controlled intersection.
- Ferreira and Krogh present the results of simulations based on a neural network model of controller scheduling for real-time switched systems. The switching strategy selects the current controller based on neural network estimates of the future system performance for each controller.
- Gao and Xu model fault diagnosis and isolation as a hybrid system and express system specifications in the duration calculus, a dense time temporal logic. An extension of program logic is used as a framework for formal verification.
- Kohn, Nerode and Remmel introduce models for multiple sensor fusion of data and for synchronization of sensors by a Noether algorithm in the calculus of variations as well as a multiple agent hybrid sensor architecture for such problems.
- Koutsoukas and Antsaklis use a class of timed Petri nets for supervisory control of hybrid systems. When the continuous dynamics are described by first order integrators, this is a linear programming problem.
- Kowalewski, Stursberg, Fritz, Graf, Hoffman, Preußig, Remelhe, Simon and Treseler explain and compare eight computer tools – six simulation packages and two verification tools – with respect to validation of logic control programs for continuous processes, with a two tanks problem as their benchmark example.
- Lafferriere, Pappas and Sastry use recent results in the model theory of first-order structures over the real numbers to establish the existence of finite bisimulation quotients for certain classes of planar hybrid systems, thus proving the decidability of verification problems for such systems.
- Lemmon and Bett build on recent results on multiple agent linear control for systems satisfying a bounded amplitude performance constraint, to give a method of extracting a timed automaton as a logical model of specified switched system behavior.
- Mosterman, Zhao and Biswas give semantics and simulation algorithms for a class of dynamical systems operating in so-called "sliding regimes." With time and space scale abstractions, these become hybrid systems with chattering.

- Nadjm-Tehrani gives a model of time deterministic hybrid systems in which transitions can have different delays and gives a transition system semantics closed under various operations including parallel composition.
- Neller transforms initialized bounded-time safety problems for hybrid systems into global optimization problems starting with an initial safety estimate, and compares the results with simulated annealing and multi-level single linkage methods.
- Parisini and Sacone analyze mode switching control policies for switched systems as two-level hybrid control schemes; they prove an invariance result for such schemes and report on simulation results.
- Raisch, Klein, O'Young, Meder and Itigin give a methodology for approximating continuous plant models by non-deterministic discrete automata and synthesizing discrete supervisory control for the approximation. The methodology is illustrated by two examples from process control.
- Rönkko and Ravn extend the action system framework for distributed and reactive systems to hybrid systems with differential equation actions and evolution guards; an extended notion of parallel composition for hybrid action systems is also developed.
- Seibel, Farines and Cury describe a methodology for the design of flight plans for rotary-wing unmanned aerial vehicles based on formal verification using linear hybrid automata.
- Skafadis, Evans, Mareels and Nerode present a solution to certain problems in mode switching controller design for stochastic dynamical systems with quadratic cost design, using dynamic programming to extract the desired control.
- Wang, Khargonekar and Beydoun investigate robust control of hybrid systems in the presence of modeling errors and structural uncertainties. For a class of non-linear hybrid systems, they develop a design methodology for hybrid state feedback based on system performance and prove robust stability results.
- Wong-Toi reduces problems of initialized rectangular automata to linear hybrid automata, yielding semialgebraic algorithms for analyzing slope parameters. Automated analysis is used to extract bounds on independent clock drifts in an audio control protocol. The emptiness problem for slope-parametric rectangular automata is proven undecidable.
- Yu and Chen present a control framework for interval temporal systems, using the duration calculus to express properties of open- and closed-loop behavior.
- Zhao, Loh and May describe their phase-space nonlinear control toolbox for synthesizing and evaluating control laws for a wide class of nonlinear systems. The maglev project is used as a testbed.

Acknowledgments: We thank the following organizers of HS97: Panos Antsaklis, General Chair and organizing committee; Michael Lemmon, Program Chair; Wolf Kohn, organizing committee; Anil Nerode, organizing committee;

Shankar Shastry, organizing committee, and the remainder of the program committee: R. Alur, M. Branicky, B. Egardt, T. Henzinger, B. Krogh, J. Lygeros, O. Maler, A.S. Morse, S. Nadjm-Tehrani, J. Raisch, H. Schumacher, and J. Sifakis. Sponsors were the National Science Foundation, the MURI "An Integrated Approach to Intelligent Systems", DAAH04-96-1-0341 administered by the Army Research Office, the Center for Foundations of Intelligent Systems (Cornell), and the University of Notre Dame. The IEEE Control Systems Society was the technical cosponsor. We are also deeply indebted to J. Davoren and A. Walz for technical editing, manuscript preparation and the administration associated with the volume.

December 1998

Panos Antsaklis, Notre Dame, IN
Wolf Kohn, Bellevue, WA
Michael Lemmon, Notre Dame, IN
Anil Nerode, Ithaca, NY
Shankar Sastry, Berkeley, CA